The Zeiss Works

And

The Carl Zeiss Stiftung in Jena.

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(Translation.)

. . By . .

FELIX AUERBACH.

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Fig. 65. The Zeiss Optical Works in 1902.

THE ZEISS WORKS

AND

THE CARL-ZEISS STIFTUNG IN JENA

Their Scientific, Technical and Sociological Development and Importance Popularly Described

BY

FELIX AUERBACH.

Translated from the Second German Edition

BY

SIEGFRIED F. PAUL

AND

FREDERIC J. CHESHIRE, F.R.M.S.,

LECTURER ON PHYSICS AT THE BIRKBECK COLLEGE, LONDON.

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Preface to the First German Edition.

IT may, at the first glance, appear strange that an enterprise, the scientific, social and technical organisation of which is of such an exceptional character, as that of the Zeiss Works at Jena, has not hitherto found an historian.* But on further consideration the reason for this will become obvious. The persons best fitted for such a task, the men actually and constantly labouring for the welfare of an undertaking, the growth and development of which has surpassed all expectation, have neither the time nor the inclination to look backwards and to gather up the threads of the past. And for an outsider it is extremely difficult so to identify himself with the spirit of the place, as not only to paint a picture that is true, both in general outline and in detail, but at the same time to do full justice to the motives of the persons who have made the place what it is. And this latter point is of vital importance, as many erroneous, not to say false, views have been widely circulated, more especially in regard to the social organisation of the enterprise.

The writer of these lines has for more than ten years been in a position to observe closely the development of the Zeiss enterprise, to become intimately acquainted with the spirit that animates

*The only production of any considerable length heretofore published respecting the Carl-Zeiss Stiftung is that from the pen of Julius Piersdorff, entitled "The Carl-Zeiss Stiftung—an effort towards the development of an Industrial labour code," Leipsic, 1897: reprinted from Schmoller's Jahrbuch, Vol. 21, Part 2. Besides this there are but a number of newspaper and magazine articles. In the compilation of the present work practically nothing but official material has been used. This material comprises the Statutes of the Stiftung; reports, speeches, lectures and memoirs by Abbe, Czapski and others; as well as the catalogues and prospectuses of the firms of Carl Zeiss, and Schott & Genossen. This general statement is made here to avoid the necessity of elsewhere indicating the sources of information.

it, and to maintain intimate relations with its leading personalities. The present book is the outcome of his long-cherished desire to attempt the record of its development. The collecting and arranging of the requisite material, especially that of an historical and statistical character, was a task of no small difficulty; and it could not have been brought to a successful issue without the co-operation and assistance of some of the scientific workers connected with the firm of Carl Zeiss, who, in spite of their many and pressing duties, have yet found time to interest themselves in the work. Without mentioning any of them individually, the writer takes advantage of the present opportunity to express to all of them his most sincere thanks.

The assistance above referred to, of course, relates only to the collection of material; the entire responsibility for the book itself rests with the writer.

The tables and diagrams are for convenience placed at the end of the book. The majority of the illustrations are reproductions of photographs taken at the Works.

DR. FELIX AUERBACH,
University Professor.

Jena, May, 1903

Preface to the Second German Edition.

THE fact that the first edition of this book has been sold in little more than half a year is for me, in the first place, a very gratifying indication of the existence of a general interest in the firm of Carl Zeiss and the Carl-Zeiss Stiftung, with their unparalleled organisation and magnificent work. In the second place I may, I trust, be pardoned in assuming that this fact is also a testimony that I have succeeded in presenting the subject in an attractive style and form.

Although but little alteration has been made in the text, the business being a very progressive one, some new articles had to be noticed in the technical part, and in accordance with a generally expressed desire, I have considerably modified some of the sociological chapters, especially those on wages, the eight-hours' day, and profit-sharing. Some new illustrations have also been added.

Permit me again to express my heartfelt gratitude to the many friends who have assisted me in preparing this edition.

F. AUERBACH.

Jena, February, 1904.

Translators' Preface.

IN endeavouring to place before the English-speaking public a rendering of Professor Auerbach's book, we have been guided, above all, by the desire to do justice to the spirit rather than to the letter of the original. Any book relating to the history of so well-known and eminent a firm as that of Carl Zeiss is, of course, certain to appeal to all interested in optical matters, no matter whether directly or indirectly. But the account of the Carl Zeiss Works, and the Carl-Zeiss Stiftung, appeals to a much wider circle. It is by no means as well known as it ought to be, at least in England, that the Jena enterprise is distinguished, not only by the excellence and variety of the instruments turned out by its workshops, but even more by the unique character of its organisation and the conduct of its business.

The Carl-Zeiss Stiftung, the child of Abbe's brain, is an attempt at social organisation of so novel and important a character that every political economist and social reformer should become acquainted with its characteristic features. The hope that by translating Professor Auerbach's book we shall have done something to spread the knowledge of a most remarkable and successful attempt to establish a better understanding between workers and employers, and thereby to contribute, however modestly, to the solution of perhaps the most difficult social problem of our generation, has not been the least of the inducements which led us to undertake our task.

It will be noticed that we have not attempted to translate the German word "Stiftung." We felt that as there is no word in English which accurately renders its meaning, it would be better to retain the original rather than translate it by a word, such as "Trust," which would have had a tendency to mislead and perhaps prejudice the reader.

SIEGFRIED F. PAUL.

FREDERIC J. CHESHIRE.

London, October, 1904.

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Introduction.

IF it be true that the interest of a book grows on the reader in proportion as he recognises the unity of purpose amidst the complexity of incident, and is enabled to follow the progress from the particular to the general, from the ordinary to the extraordinary, the following pages may be expected to interest a large circle of readers. We are about to describe, in all its aspects, historical and social, as well as scientific and technical, one of the many large industrial undertakings which supply the needs of Man. All these aspects, however, as we shall see, are united by a common bond, tend towards a common end, and are dominated by a common idea, inasmuch as they all have for object, so to regulate labour that it shall actually become, as Scripture tells us it is, man's most precious possession; so to re-adjust it in every particular that it shall cease to be the cross of life and become its crown.

None of the ideas and tendencies of which we shall speak, neither the scientific nor the technical, nor finally, the social, are new. Undoubtedly they have lain dormant in many minds for a long period; occasionally they have even awakened to a kind of shadowy realisation. But they have led to so many failures, that despite some partial successes, one may easily be led to doubt their truth. Such statements as "Technics must be founded on Science," "The interests of the employer and employee are identical," and the like, however much they may differ amongst themselves, have yet one thing in common, namely, that it is easy to show that they lead to apparent contradictions, whilst it is difficult to prove that they are, notwithstanding these apparent contradictions, true. It is the peculiarity of all such ideas, that if not logically developed with the utmost rigour, in spite of all apparent mental obstacles, they lead to a negative instead of to a positive goal; that is to say,

they end in a more or less defined suspicion that whilst, no doubt, in theory true and beautiful, they cannot well be reduced to practice. It is the old story of the independence of thought and the interdependence of realities, and the conflict between them. The thought that this state of conflict, which is no doubt to a certain extent real, is inevitable, had first to be overcome; unshakeable conviction and iron will were needed to prove that it exists only as long as actualities are ignored or fought against; but that as soon as they are taken into account and utilised it ceases to exist. To express it differently: The cardinal principle of optimism had to come into operation—the conviction, that is to say, that every clear and consistent conception is capable of realisation. On this basis alone was it possible to erect a structure in which the various parts that go to make up the whole are made and fitted together consistently with pure abstract thought, and which, in spite of many adverse prophecies, still stands firm and unshaken.

Opto-Technics.

THE department of industry, that is to say, Opto-technics, to which the enterprise with which we have to deal belongs, occupies a peculiar position in relation to the entire field of human activity. If we wish to compare it with some other department with which the general reader is somewhat more familiar, we are obliged to fall back on Electro-technics; yet although there is much which is common to these departments, there is perhaps even more in which they differ. They have this much in common,—both are branches of the science of physics: the first is a branch of Optics, and the second a branch of Electricity and Magnetism. Both of them, too, are closely dependent on Chemistry—the first in regard to the technology of optical glasses, the second in regard to Electro-chemistry. Both, in a somewhat similar manner, have developed beyond the limits of abstract science, and have given rise to technics which the mere scientist, however well he may be versed in the branch of abstract science in question, cannot understand without special study. Finally, they have the common feature that both make the highest possible demands on all engaged in them, from the man who directs and supervises, down to the manual worker; a fact of which the external manifestation is the high remuneration given both in salaries and wages, and the shortness of the working day.

But to come to the feature which differentiates them,—the subject of Electro-technics has developed at a rate which has left Opto-technics far behind. Within a comparatively short period it has managed to attain a position of such importance in the industrial world, that the position occupied by its elder sister—Opto-technics—seems in comparison small and unimportant. This is, of course, simply due to the fact that the ways in which electricity can be utilised are so much more numerous. Electricity gives power and light; it facilitates the intercourse of human beings, and the transmission of objects and news; it reacts on chemical substances

and on the human organism. It is largely in request, therefore, in the technical world. Light, it is true, does work also, and within very recent times we have succeeded in measuring the pressure of light radiation, and in determining the mechanical equivalents of light-sources. But in all the work light does, as, for instance, in bleaching, in accelerating growth, and the like, there is very little room for technical optics. Leaving these processes out of account, we are obliged to confess that light possesses practically but one important property, which, however, can be made manifest in many and different ways: it enables us to see, and to produce images. Light, speaking from this point of view, does not create, it only reveals; it is the handmaid, not of action, but of perception. The task of Opto-technics consists in extending the field of vision beyond the ordinary limitations of space and time, due, it may be, to the object being too small or too far distant to be seen clearly and distinguished from its surroundings, or of such a character that it does not stand out with sufficient relief. Again, it may be desired to fix brief and changing impressions permanently on the photographic plate, or to measure not only what is seen, but even what by itself cannot be seen. We have thus the principal branches of Applied Optics, such as the Microscopic, Telescopic, Stereoscopic and Photographic, together with the Optics of Measuring Instruments; besides these, however, there are numerous minor divisions. The subject is undoubtedly rich and varied, but it can scarcely be termed "practical," in the sense which the words "Practical Optics" seem to imply, if we leave out of account the manufacture of a few simple articles, such as spectacle glasses and the like, together with some applications of photography. This is due to the fact that it does not enter into the busy life of industrial production, being principally concerned with questions of abstract research. Some of its products, such as the range-finder or the butter refractometer, may serve practical purposes, but the most typical optical instruments, such as microscopes and telescopes, field-glasses and photographic apparatus, are almost exclusively employed by the man of science, and by the amateur who wishes either to perpetuate experience or to acquire knowledge.

The similarity, as well as the dissimilarity, between Opto-technics and Electro-technics, can be clearly traced in the history and development of two enterprises, each of which has gained a leading position in its own particular field. We refer to the firms of

Siemens and Halske in Berlin, and Carl Zeiss in Jena. Each started in the most modest manner, appealing for custom and support only to its own immediate neighbourhood, and each has developed into an undertaking, the productions of which are to be found everywhere, from Upsala to Cape Town, from San Francisco to Tokio. In both cases the gigantic development can be traced to the fact that a man, who, until that time had had no practical experience of the particular line of business, became connected with the concern; in the first case it was the artillery officer, Werner Siemens, who joined Halske; in the second it was the university don, Ernst Abbe, who joined Carl Zeiss. In both cases the success achieved has been due to the scientific direction of highly-technical skill. Both concerns were started in the same year, and to-day both are amongst the largest of their kind. Yet Siemens and Halske employ fifteen times as many workpeople as Carl Zeiss. The reason is obvious: amongst hundreds who desire to arrange their daily life as comfortably as possible, there is probably but one lover of the true and beautiful; and amongst hundreds of lovers of the true and beautiful, there is perhaps but one investigator.

The fact that, in spite of all this, the Carl-Zeiss Works to-day find constant employment for more than 1,350 people, including more than 20 scientific collaborators, and more than 80 engineers and foremen, is due to two apparently incompatible circumstances,—the perfection and variety of their productions. In the next chapter we shall show that under certain conditions these are not really so incompatible as they appear.

Limits of the Application of the Principle of Sub-Division of Labour.

IN order that an article may really excel, it must be the outcome of thorough theoretical knowledge, combined with great technical skill, and this combination of qualifications can be secured only when its maker, or to be more accurate, everyone participating in its manufacture, devotes his whole experience, intelligence and time, solely to the production of this one article. To construct, for example, a really perfect microscope, the mathematician who makes the calculations must be master of all the

formulæ required for this purpose, even if he be not master of anything else. The physicist must know everything about the paths of the rays within the microscope. Every individual workman, whether he is engaged in making the eye-piece or the objective, constructing the tube, or working on the mechanism which controls the movements of the instrument, must bring the ripest and best experience to his task. To put it shortly: the secret of success lies in the sub-division of labour. At Jena this has been carried as far as possible, with the result that everyone works only within a certain limited field, and in course of time becomes so expert, that no all-round man can, within that special field, compete with him.

It may be said that the natural consequence of this principle, if applied to the whole undertaking, would be to limit its production to articles of a single kind, as, for example, microscopes. During the first forty years of the existence of the business of Carl Zeiss, this was indeed practically the case. It might be argued that this production of a single article only, constitutes likewise a kind of division of labour. The production of all other articles is left to other manufacturers, and the whole energy of every worker is bent towards producing, for example, the most perfect microscopes. But, after all, there is a limit beyond which a principle cannot be carried without doing more harm than good. It is to Abbe's credit that he recognised that even the principle of the division of labour has its limits; and the proud position occupied to-day by the Zeiss Works is due to his recognition of this fact at the right moment. The limit is reached, either when the number of people employed in the business becomes too large in comparison with the intrinsic importance of the only article produced, the demand for which, even if it does not entirely cease, may yet vary considerably; or when the worker, suffering from the monotony of always having to work in the same groove, whether with hand or brain, has his mental vision thereby dulled for anything situated beyond his own narrow horizon, and loses the power of utilising at the right moment for his own particular purpose anything lying a little beyond his ordinary everyday path.

The people at the head of the Carl-Zeiss enterprise, influenced by considerations of this kind, have, true to the proverb "*Rast ich, so rost ich*,"* increased the number of articles manufactured; and

*"To rest is to rust."

no year now passes without the addition of one or more specialities to their list. At the present time it is no longer possible to assert of any one of the principal articles produced, whether microscope, telescope, field-glass, photographic apparatus, or measuring instrument, that it is of greater importance than any of the others. Each kind of instrument produced at Jena is none the less perfect because so many different kinds are now made there. It is to this all-round excellence that the firm owes its unique position. Rivals it has—rivals worthy of its steel—in one or other of the departments of its activity; but taken as a whole, it is unrivalled.

Early History of Optics.

TO appreciate rightly the real significance of the position occupied by the firm of Zeiss, some acquaintance at least with the history of practical optics is necessary. This history may be divided into three periods, of which the first and the last may be looked upon as scientific, whilst the intermediate period was empirical—a wave, as it were, with crests separated by a trough. In the first of these periods, when simple instruments were built in a simple fashion, the optician started from a scientific basis: He constructed his instruments in accordance with the simpler laws of geometrical optics. This was the method of the Arabs, and also of the earliest Western opticians, after the awakening due to the Renaissance. To speak allegorically, the people of that age attained to a certain elevation, which even if it was not a lofty one was the highest at that time within their reach. During the second period, opticians grew more ambitious, and attempted the solution of more intricate problems; their knowledge, however, was unfortunately not commensurate with their desire for progress and, consequently, in course of time, they entirely lost sight of the means by which alone the desired end could be attained. Attempts were made to reach the goal whilst the means by which, alone, success could be commanded were ignored; science was neglected, and a period of tentative and haphazard experiment set in. Amongst the many who buy lottery tickets there are always some who gain great prizes, for even a blind chicken, as the German proverb puts it, sometimes

finds a grain of corn; what wonder then that even during that period some progress was made, although it scarcely needs saying that its extent and importance bore no relation to the number of the people who engaged in the work, the time spent, or the trouble taken. And the successes attained were, after all, but of minor importance: on these lines the real work could not be done or the true object achieved.

Final success was reserved for the workers of the third period, the men who were clear-sighted enough to see that there was nothing further to be gained from the quagmire of haphazard experiment, and courageous enough to act up to their belief. Convinced that success, if it were to be attained at all, could be the outcome, not of mere chance, but only of the slow and laborious methods of scientific research, they determined to take their stand on the sure foundation of science, and to attack the problems to be solved by scientific methods, making sure of each step on the road before proceeding to the next. At first their voice was like that of one crying in the wilderness; for a long time it fell on deaf and unwilling ears, but the time came when even the most unwilling were forced to listen. In some parts of the field, science asserted its sway sooner, in other parts later, but gradually it has triumphed all along the line, and to-day there can be no longer any doubt that the palm has been awarded to it.

This is not the place to speak of the work of the pioneers—of what Fraunhofer and Herschel did for telescopic optics, Petzval and Steinheil for photographic optics, and others in other fields—at present we are only concerned with microscopy, and especially with the two men who have done so much to save this branch of optics from the slough into which it had fallen, and to the united action of whom the success of the Jena Works is due. We, of course, refer to Carl Zeiss and Ernst Abbe.

The New Era of Microscope Construction.

IN 1846, a small workshop for the manufacture of optical and other philosophical instruments, was opened by Carl Zeiss,* at Jena, the seat of the University of Thüringen. Taken by itself, this circumstance would not have been of more than local interest, such a business being a necessary adjunct to the medical and natural-science faculties of every university. As a rule the proprietor of such a business is quite contented if he can earn a bare living by executing such orders as may fall to his share. Zeiss, however, although of a thoroughly modest disposition, did not happen to be

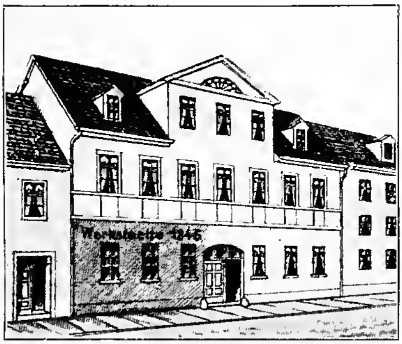

Fig. 1. First Workshop in the Neugasse.

Fig. 2. Second Workshop in the Wagnergasse.

an easily-satisfied man; he was one of those who ask more of life than the just-sufficient and do not rest till they have obtained it.

Time and place were well suited to breathe new life into the manufacture of philosophical instruments, and the study of practical optics, between which such a close connection exists. In proof of this we need only mention the name of the Jena biologist, Jacob Schleiden, the first and famous advocate of the Cellular theory, then just beginning to flourish; of his assistant Schacht; and of the

*Carl Zeiss, born September 11th, 1816, at Weimar, was the son of a toyshop proprietor, who had, at one time, acted as instructor of turning to the Grand Duke Frederick. Having passed through all the forms of the classical school except the highest, Carl was apprenticed, and served his time in the mechanical and engineering trade at Weimar, Stuttgart, and Vienna. In 1846 he founded the firm of Carl Zeiss, which has since then developed to such an enormous extent. In 1881 the University of Jena conferred upon him the honorary degree of Doctor of Philosophy, in recognition of his services to science. He died December 3rd, 1888.

well-known teacher of medicine, Domrich. Not much assistance could be expected from the microscope apparatus of that time in solving the problems in which these and other leading scientists were interested. It was most probably the recognition of this fact, that induced Schleiden to persuade Zeiss to devote himself more and more to optics. Throughout the career of Zeiss, Schleiden followed his progress with active interest.*

In the beginning everything went well. Zeiss manufactured microscopes, no better and no worse than those manufactured in well-known and old-established optical workshops, but as soon as he attempted to strike out on new lines he realised the deficiency of his equipment. He was, therefore, confronted with the necessity of deciding whether he should remain satisfied with the attainment of the common standard, or whether by calling in assistance he should make an attempt to meet more fully the requirements of modern science. To have chosen the second alternative, to try to steer his ship towards the open ocean, showed courage; to try to do so, not by himself, but with the assistance of a pilot, showed wisdom; and wisdom and courage combined attain an almost certain reward.

But the simile of a pilot, like every other simile, is only applicable to a limited extent. A pilot is one who thoroughly knows the channels through which he has to guide the ship entrusted to his care; but in the case in question, the channels themselves were unknown; no course had as yet been mapped out. The experience necessary for the production of a microscope constructed on strictly scientific principles, had not as yet been attained by anyone. The man required, therefore, was one who should combine with the necessary capacity and enthusiasm for the task a clear recognition of the fact that success could not be expected until after long and persistent labour, involving perhaps, the surmounting of great and unforeseen difficulties. Considering the unique qualifications required, it is not remark-

*As early as the year 1857 Schleiden had given Zeiss a testimonial, in which he said: "Mr. Zeiss has asked me for a recommendation; I really do not know why. My testimony can only be valuable as a recommendation for his optical instruments, and these no longer require a recommendation from anyone. Mr. Zeiss states that his microscopes are at best but tentative experiments; his modesty is as much to his credit as his intelligence and skill. The optical parts of his instruments need not fear to enter into competition with the productions of old established firms. What he has already achieved justifies us in expecting that he will turn out instruments not only as good, but even better, than any that have heretofore been produced. . . . ."

able that Carl Zeiss did not at first succeed in his quest. One pilot failed him before Ernst Abbe* stepped on board to steer the ship to the open sea of success.

But to return to our subject. Even the best microscopes of the period we are referring to, although, of course, based upon the fundamental laws of geometrical optics, were but tentative productions. The necessary lenses for the eye-piece and the objective were first ground and polished, and then tested to ascertain the quality of the images of microscopic objects which they presented to the eye. In this way sufficient knowledge and experience had been gradually accumulated to determine the shape of the lenses necessary to fulfil certain conditions, or, to be more accurate, to avoid certain defects, such as want of definition; unequal magnification in the middle and towards the edges of the field of view; coloured borders; insufficient brightness and the like. When the dimensions of the lenses were altered with the object of avoiding one or the other of these defects, it was usually found, that even if the desired object had been attained, other defects had been rendered more pronounced. Further alterations were usually attended with much the same result. As a perfect optical image can only be obtained by the satisfaction of a great number of conditions, it is safe to assume that had matters progressed only along the lines indicated, centuries might have elapsed before the production of a single ideal microscope. It is indeed difficult to see how it could have been produced at any time except as the result of a fortuitous accident.

There was only one way to abolish, once and for all, these trial-and-error methods, and that was to replace the rough approximations to the ray-path by more exact mathematical determinations,

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*Ernst Abbe, born January 23rd, 1840, was the son of a foreman in Eichel's spinning mill at Eisenbach. He studied at Jena and Göttingen, where he took his degree, taking for his thesis the subject of the mechanical equivalent of heat. He taught for some time at Frankfort-on-Main, and established himself at Jena, in 1863, as a university tutor in Mathematics, Physics, and Astronomy, taking for his treatise the subject of the estimation of errors. In 1866 he became connected with Zeiss, and in 1870 he was appointed as an extraordinary professor. When in 1874 it was proposed to establish a physical institute at Jena, the charge of it, together with an ordinary professorship of physics, was offered to Abbe, but, situated as he then was, he was compelled to decline the offer. Abbe, who is also a member of many learned societies. has had the honorary degree of Doctor of Medicine conferred on him by the University of Halle, and the honorary degree of Doctor of Law by the University of Jena. In 1871 he married a daughter of his former teacher, Professor Snell, by whom he has had two daughters.

which, expressed in cast-iron formulæ, should enable the necessary structural elements of the lenses, such as thicknesses, diameters, radii of curvature, etc., to be exactly determined by calculation simply and alone. Only in this way, it was seen, could an instrument be produced free from all but absolutely unavoidable defects.

It does not require much consideration to realise that formulæ capable of satisfying, even approximately, these conditions, must be of a very intricate character; and that the more closely the conditions are satisfied, the more intricate must the formulæ become. Consequently the obvious mode of procedure was to start with a simple formula, representing, so to speak, a first approximation to the ideal, and then to proceed by successively closer approximations towards the desired goal.

But accurate formulæ were not the only requisite for the attainment of the goal; it was also necessary to so improve and develop the technical methods of making and constructing optical instruments as to render practicable the exact execution of precisely formulated tasks at all stages of the advance to the ideal. For instance, whilst the allowable deviation from a desired thickness, or a desired radius of curvature, might at first have amounted to a twentieth of the whole, it would probably have been necessary to reduce it in time to a fiftieth, a hundredth, or even less.

To determine whether the accuracy obtained in optical work is really within the limits laid down requires very accurate methods of testing. Thus the most exact method of testing the curvature of a surface, the most important structural element to be obtained, is based upon the production of Newton's rings, which can be observed whenever two surfaces of slightly different degrees of curvature are laid one upon the other, and which disappear, when, as in testing, the curvature of the lens surface to be tested is exactly equal and opposite to that of the standard surface. Although this method of testing lenses was first applied by Fraunhofer to the testing of telescope object-glasses, the credit of having introduced it at Jena must be given to August Löber—Jena's oldest foreman—a man who, by the facility with which he grappled with the most intricate and subtle technical difficulties, contributed his full share to the development of the Jena Works. The perfecting of the methods of testing which have been gradually effected is of an importance which must not be under-estimated. Special apparatus has been devised for testing the curvatures, thicknesses, and the centreing of lenses, the flatness of surfaces, and the distances between the different parts of a lens system.

But to return once more to our subject: the scientific determination in advance of the data to be adopted for the satisfying of the desired conditions. We have already shown, that were it only on account of the mathematical difficulties, the approach towards the ideal must be effected by slow steps; that a beginning must be made with simple formulæ, satisfying at first the principal conditions only, but which can be gradually modified to adapt them to satisfy further conditions. But one thing had to be insisted upon as a matter of principle. Right or wrong, the workman was called upon to work strictly to the theoretically determined measurements given to him. Whether the result was satisfactory or not, did not matter, so far as he was concerned, so long as it conformed accurately to the specification provided.

But in this lay a great danger to the impatient reformer. It might happen—nay it was certain to happen—that the first products of the scientific method in optics—the results of the first approximation—would not be so perfect as the best products of the old and empirical method, which had long years of accumulated experience to fall back upon. This experience, it is true, was also in the possession of the workers at Jena, but as we have explained, they could no longer avail themselves of it. Our reformers, however, were prepared for initial failure. Instead of losing courage, they consoled themselves with the thought that no goal worth striving for had ever been reached at the first attempt; and their belief in ultimate success was invincible.

And now to appreciate fully the credit due to Carl Zeiss—nothing need be said of that due to Abbe—we must imagine a simple modest man, only dimly able to comprehend the talk around him, who, after listening all day to discussions about formulæ, drawings and figures, by means of which new plans were to be realised, devoted his evenings to study, to fit himself as best he might, for a right understanding of the questions discussed; a man whose business progressed fairly well, and would in all probability have continued to do so, and who yet, in spite of all this, was willing to run a risk, which, at that time especially, caused a universal shaking of heads. Practical men have never thought much of science, and, especially when considering difficult technical problems, have always said: "Science cannot help us here." Even many years later a respected and learned writer on microscopy, who was intimately acquainted with one of the most experienced opticians of the old school, and consequently knew the subject well, asserted that microscopes were too complicated to be

constructed in accordance with theoretical requirements. For a long time makers of optical instruments used to recommend tneir microscopes by stating that they were not like those made at Jena;

Fig. 3. Carl Zeiss.

a recommendation which was not until much later changed into the opposite statement.

It was, in itself, no small matter for a man with the educational limitations of Zeiss to uphold, in opposition to the almost universal opinion of his time, unhesitatingly and courageously the

standard of science. And it must further be remembered that he had already made one abortive attempt, and that even the second attempt, under Abbe's guidance, did not at first promise success. Consequently it did not seem at all improbable that he would, after repeated and long-continued sacrifices, find himself, with resources exhausted, face to face with ruin. If that had resulted, anyone speaking nowadays of the Jena Works of Messrs. Smith and Robinson, for the manufacture of optical instruments, would probably say that its first proprietor was a certain Carl Zeiss, who ruined himself by embarking on Utopian projects. But Carl Zeiss did not ruin himself; on the contrary the unknown university mechanician became the world-renowned optician, and, as we shall see later on, attained to even greater heights.

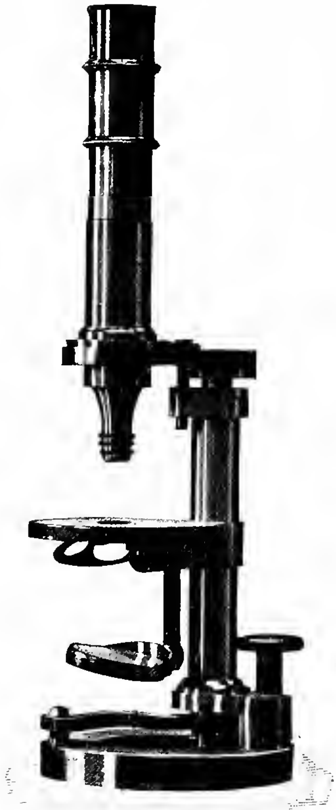

Fig. 4. Microscope Stand (1859).

The best conception of the real eminence of Carl Zeiss is perhaps gained by comparing him with two men, both, individually considered, so great that at the first glance such a comparison must appear absurd. But in making comparisons relative rather than absolute magnitude must be taken into account; individuals cannot be truly and fairly judged without regard being paid to the time and circumstances under which they lived and worked.

The first comparison then is with Joseph Fraunhofer, the man who started life as a poor lens-grinder, and died one of the greatest of physicists and opticians. When we remember that Fraunhofer, nearly half a century before the time of Zeiss and Abbe, declared that success in practical optics could only be achieved by observing the most minute scientific precision, and carried out all his work in strict conformity with this principle, it almost seems as if the greater part of the praise which we have given to Zeiss and

Abbe was really his due, although his work, the construction of telescopes, lay in a different branch of optics. It might, at first sight, appear that they had only imitated his example and mechanically applied to the microscope the principles already applied by him to the telescope. But this was by no means the case.

A careful survey of all the surrounding circumstances points to the conclusion, that while Fraunhofer's work may have suggested the application of the same guiding principle to the construction of the microscope, it could not possibly have offered any assistance in the actual realisation of the idea; in spite of the seemingly close relation of the problems involved. This conclusion, which may appear strange at first, is based on the essential difference, theoretical as well as practical, which exists between the two principal problems of practical optics, the telescope and the microscope; a difference only recently recognised, and to the tardy recognition of which is due the fact that the problem of the scientific construction of the microscope still demanded a solution, even long after the corresponding problem for the telescope had been solved.

The other individual with whom Zeiss may be compared, was occupied in a very different branch of industry—the manufacture of steel and iron, and more especially that of ordnance. We refer to Alfred Krupp. He too started in a very small way, and finally left all his rivals far behind. His success, like that of Zeiss, was largely due to the possession of mental faculties of a high order, which led him with iron perseverance to continue year after year his experiments, in the face of constantly-threatening ruin, but in the invincible belief that they must be successful sooner or later, since they were carried out in strict conformity with the dictates of science; even down to the smallest details he had calculated beforehand the properties of his cast-steel tubes.

Ernst Abbe.

WE have drawn the mental image of a man who joined the great majority years ago. We have spoken of him "*nil nisi bene*," not because the proverb wills it so, but because it has been impossible to speak otherwise. Now we turn to the survivor, and at the risk, perhaps, of showing some want of consideration for his wishes, make him the subject of our remarks. No proverb exists that forbids us from speaking well of the living. We shall but state the facts, we shall say only what must be said to give an accurate and faithful account of the foundation of the Jena Works.

Whilst it is doubtless true that the great firm of Carl Zeiss would not now exist if it had not been for the personality, intelligence, and character of its founder, it is, notwithstanding, equally true that it could not have become what it is without the co-operation of Abbe. No one asserts that Zeiss alone could have achieved so much. He, however, found in Abbe just the one man who understood the problem to be attacked, comprehended its importance, and being rarely gifted for the work, was willing to devote to it the whole of his great powers. Truly it was a disposition of Providence that induced Zeiss to look close at hand rather than afar for the man he wanted. If his mind had run in the ordinary grooves of the shrewd business man, he would probably have obtained a list of all the men who had already gained, either at home or abroad, a reputation as workers in the field of practical optics, and from it have chosen the most eminent. Abbe's name, however, would not have been included in such a list, because up to that time his interest had been in theoretical optics only. It is not, of course, possible to state definitely what course events would have taken if Zeiss had acted in this way, but it is difficult to believe that any success which might have been achieved could have equalled that actually achieved, and this for a reason which may at first appear paradoxical: Abbe was ignorant of practical optics. It is doubtless true that the great majority of problems, the solutions of which are mile-stones on the road of progress, need to be attacked by experts of specialised experience and training; but it is equally true that the very greatest of all, those that are of epoch-making importance, form an exception to the rule. They are most likely to be successfully overcome by men who bring a fresh mind to the task, a mind unfettered by rules, and

one that is not, by too great a deference to authority, prevented from accepting its own conclusions.* In this connection it is only necessary to mention Faraday and magnetic induction; Fraunhofer and spectrum analysis; Mayer and the conservation of energy.

There still remains to be taken into account something that concerns less the intellectual than the purely human aspect. It is not every man that could have worked in such complete harmony as Abbe did, with a man so different in nature and so differently trained as Zeiss was. Not only did he succeed in doing this, but he at the same time inspired him and the entire staff of the firm with enthusiasm to undertake strange and unpromising tasks. Only a man capable of employing his whole intellectual superiority for the accomplishment of his end, whilst at the same time preventing his fellow-workers from feeling this superiority in the most distant manner, could have succeeded in such an undertaking. There are chapters in the history of practical optics, the tragedy of which is due to the fact that the theorist and the practical man were not in the long run willing to sink their separate individualities in the presence of their great task. Zeiss and Abbe, on the other hand, supply a remarkable instance of the possibility of co-operation between two totally diverse characters, and of the signal success thus obtainable. It is difficult to say which is more worthy of admiration; the manner in which the experienced man of business approached the young scientist, or that in which the deep thinker met the simple man of action; both working hand in hand to reach the desired goal, single-minded, with but one object before them.

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*The following circumstance supplies an interesting illustration of our theory: Helmholtz had already pondered over the problem of the microscope, but had contented himself with the result that there was an inexplicable contradiction between the facts and the theory. He could not find any concealed error, and it did not strike him that the whole basis of the theory might be wrong. He was very much surprised when he heard about Abbe's work, and went specially to Jena to have it more clearly explained to him.

The Formation of Images of Non-Luminous Objects.

IN the preceding chapter we gave a general outline of the extent of Abbe's activity; in this one we shall consider somewhat more in detail his influence on the theory and practice of microscope construction.

We know that the problem which confronted Abbe was the theoretical determination in advance, of the data required for the construction of microscope systems, so that there should remain no longer any necessity for the experimental trial-and-error gropings of the lens grinder and polisher. We know further that prudence required that the problem should, at least at first, be narrowed and simplified as much as possible, by taking into consideration only conditions under which the path of the ray is, in theory, relatively simple. It had long been supposed that these conditions obtain, when very narrow pencils only are considered—pencils in which the marginal parts are stopped out by small diaphragms. But when Abbe, starting with this assumption—and none other was known at the time—began to calculate, to construct, and then to observe, he soon found that there was an error somewhere, because not only did the microscope images not become better with the narrowing of the diaphragms, but, on the contrary, they became worse and finally disappeared altogether, although there could be no doubt as to the sufficiency of the light employed.

There was only one possible conclusion that could be drawn from these results, but to draw it required a courage and independence in scientific questions so great as to be but rarely found even amongst the most eminent intellectually. Even Helmholtz, who when engaged on the same subject, found that the facts and the theory did not agree, accepted the contradiction as something which could not be explained. Abbe did not. He boldly maintained that the old and time-honoured theory of the formation of microscope images was wrong. Thus far his criticism was destructive rather than constructive, but he did not stop here. To the inquiry why is the theory false, and what is the correct one? Abbe gave a remarkable reply. Nothing characterises the man more than the fact that he, who undoubtedly felt that science was indebted to him for a great step forward, kept his discovery, the announcement of which would have gained him fame near and far,

secret, only anxious to apply the principle discovered to the construction of his microscope. It is due to this fact that his theory, which dates from 1870, did not become known in scientific circles until many years later, and great was the astonishment of those who witnessed his experiments at the Congress of German Scientists at Halle, in 1891, when they were told that the discovery was already more than twenty years old.*

What is the new theory? As we are not writing for scientists we can state it in general terms only.

It has been known since Fraunhofer's time that the more delicate details of an image, projected by a lens or a mirror, are not determined strictly in accordance with the laws of geometrical optics, that is, they do not depend solely on the path of the ray, as calculated by the laws of refraction and reflection, but are influenced also by the diffraction effects due to the wave character of light.

A mirror or a lens may be looked upon in the first instance as an obstacle to the march of the train of ether-waves originating from a self-luminous point. They interfere with this march in a somewhat similar way to that in which a rock in the sea interferes with the progress of the waves; or as a freshly-tilled field with the manœuvring of soldiers. The object of the optician is to so choose and design these obstacles that the trains of ether-waves are not, as it were, shattered and destroyed by striking them, but are simply transformed into other trains of ether-waves

*Abbe published in 1873 a "Preliminary Notice" in Max Schultze's "Archiv für mikroscopische Anatomie." The printing of a complete account was begun in 1881, but was never published, because of the absorption of Abbe's time and interest by the production of the new glasses. Consequently the first complete and popular account of the theory is the one given in the 2nd edition of Dippel's "Manual of Microscopy." A strictly scientific exposition, read by Abbe to a small circle of his students has, as yet, not been published. We may here state that Abbe, in accordance with his whole view of life, and in the strain and stress of a very active career, did not attach much importance to the publication of his studies and discoveries, especially as there did not at that time exist, at all events in Germany, either suitable organs for the publication of articles dealing with such subjects, or a sufficiently large number of appreciative readers. It is therefore satisfactory to know that the void, which had increasingly made itself felt as time went on, has been practically filled up by the publication of the three following works:—

1. *Theory of Optical Instruments.* S. Czapski. Breslau, 1893. A second and enlarged edition is in the press. (This book forms also Part I. of Vol. VI. of Winkelmann's *Manual of Physics*).

2. *The Collected Papers of Ernst Abbe.* Vol. I. Jena, 1904.

3. *The Theory of Optical Instruments.* Vol. I. *The Theory of the Formation of Images, etc.*, edited by M. v. Rohr. Berlin, 1904.

converging to a new centre or point, which is the image of the point from which the first waves originated. After passing this image point, the waves again spread out, in a similar manner to that in which the waves spread out from the first luminous point. Similarly, but yet somewhat differently, more exact experimental observation shows that the smaller the angular magnitude of the cones described by the effective waves originating from the first centre, which are obstructed, diffracted, and transformed into a new series of waves with another centre by the lenses or mirrors, the less likely is the new centre to resemble a point, and the more likely it is to develope into a disc-like surface. To adopt the langnage of the theory of the formation of images: the smaller the angular aperture of the system the more indistinct, wanting in detail and coarse-grained the image will be; on the other hand, the greater the angular aperture, the more distinct, rich in detail and fine-grained will be the image. It follows from this that it is impossible to expect any image ever to be absolutely perfect, point like, and showing new detail for every increase of the magnification, because even an angular aperture of 180° gives an image with a certain amount of grain.

It is to Helmholtz that credit is due for applying these considerations to the study of the microscope system, the angular aperture of which, on account of its magnitude—it may be as great as 180°—renders it difficult to determine mathematically the optical action of the system. Some of his mathematical results showed a surprising disagreement with experimental facts, a result for which he was unable to give any explanation.

The great discovery shortly before made by Abbe, consisted in the recognition of the fact that in the ordinary use of the microscope, the individual points of the object cannot be considered as independent sources of ether-waves, because, since the microscopic objects are examined with the aid of transmitted light, it follows that the wave centres are situated not in the microscopic objects, but in the real source of light, that is to say, in the flame of the lamp used, as a consequence of which "diffraction" is produced, primarily by the object. We cannot here explain how Abbe has developed this theory—a theory which at the first glance, seems to introduce an extraordinary number of complications—in such a manner that the influence of all the determining factors, the source of light, the object, the optical system and especially the angle of aperture, can be recognised clearly and accurately. We can only say, that the extent to which the light waves, diffracted

by the object, enter into the formation of the image depends on the angular aperture of the system, upon which also the distinctness of the image depends.

But in the microscope—in the production of images of non-

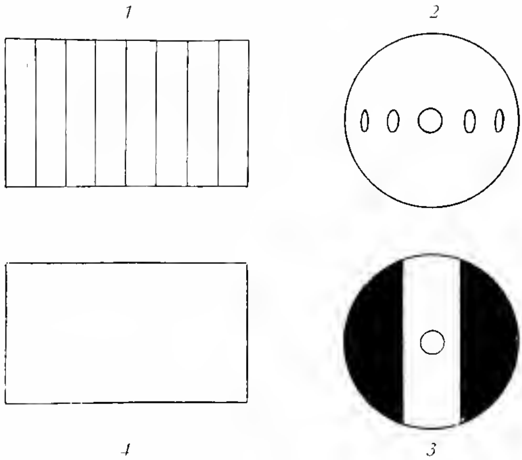


Fig. 5.

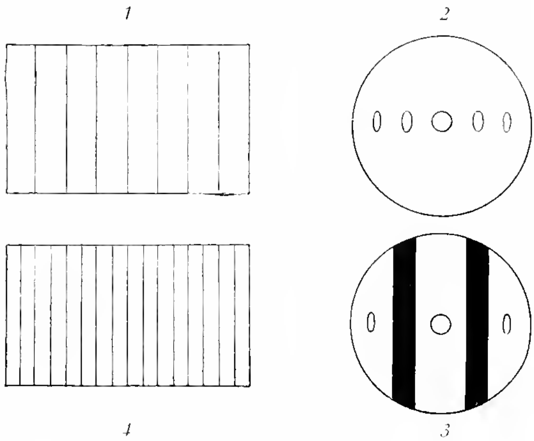


Fig. 6.

luminous objects—we encounter a further phenomenon which constitutes the new and really interesting part of the discovery. In consequence of part only of the waves, originating in the source of light, participating in the diffraction process the image obtained

is not only indistinct, but in many cases is quite different from the object. This was shown in a striking way in the experiments made at Halle by means of a stop in the upper focal plane of the objective, which artificially cut off some of the rays of the light usually utilised for the formation of an image of an object. In this way a ruled screen (1), Fig. 5, can be imaged as a uniform and undifferentiated gray surface (4), by using the stop (3) to cut out, as shown, part of the diffraction pattern (2) found in the upper focal plane of the objective; the image of a screen (1), Fig. 6, can be changed similarly to one in which the

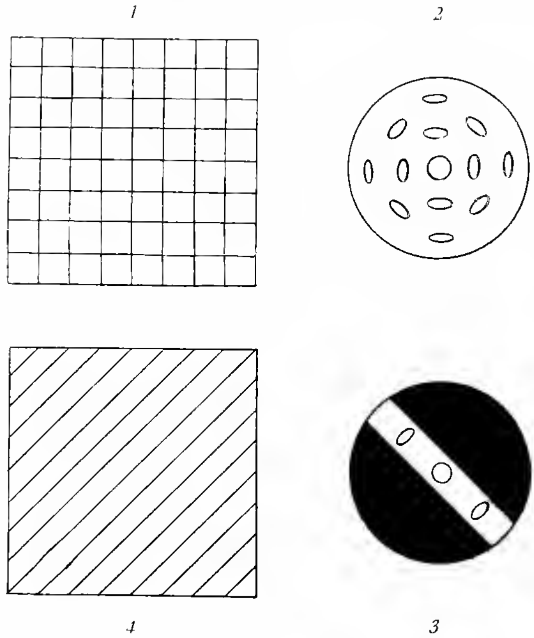


Fig. 7.

width of the intervals is halved (4), by the use of a stop (3); or a cross-ruled screen (1), Fig. 7, may be imaged as a number of diagonal lines (4), by the use of a stop (3). These effects are due to the fact that the different parts of an image do not originate from individual rays, but that all the rays assist in producing each and every part of the image, and therefore, if some of the rays are cut off, not part only, but the whole of the image suffers. It is therefore no longer surprising that the older types of microscope systems produced only distorted images, breaking up, as they did, the systems of light waves. That this does not occur

to a greater extent than the nature of light renders unavoidable, constitutes the principal advantage of the new over the older microscope systems.

But this advantage could only be realised, firstly, by using objective systems of much greater optical perfection to allow of the employment of greater angular apertures, and, secondly, by effecting a whole series of secondary improvements, of which we can here refer to one only—Abbe's illuminating apparatus. This apparatus makes it possible to change arbitrarily within certain wide limits the apertures as well as the directions of the incident cones of illuminating rays, and thus utilise to the full the capacity of the perfected objective systems.

The New Glass.

HITHERTO we have only discussed the forms which the lenses should have to give the best possible images. But the path of the light depends on still another factor, namely, on the material of which the lenses are made. It may be said that many words need not be wasted on this subject, as glass is the only possible material. But this, as we shall see, would not be quite correct, although by far the greatest number of lenses are made of glass. The real cause of misunderstanding lies, however, in the use of the word "glass." If it is said that an object is made of metal, the question is put: "What metal? copper or iron, bronze or brass?" Metals are of the most diverse character. The word "metal" is simply a generic term. That the same is true of the word "glass" is scarcely so well known. Glass is manufactured by melting together minerals, acids, oxides, earths and similar substances, and the number of the different kinds is quite as great as that of the metals. Of course, not all substances melted together produce glass; and those which do, must be mixed in certain definite proportions. In many cases crystals are formed, but it is a characteristic feature of glass that it is amorphous or non-crystalline. Even when glass is obtained, it is sometimes of such a kind that it cannot be used, at all events for optical purposes. It may not be durable, or sufficiently transparent, or sufficiently colourless. But granting all this, there still remain thousands of possible combinations of materials capable of producing glass.

The number of different kinds of glass made by glass manufacturers prior to the latter portion of the 19th century was, notwithstanding, very limited. Practically only two kinds were made, crown glass and flint glass, both of them consisting principally of silicic acid, soda and potash, to which, for flint glass, lead oxide was added. In crown glass, the refractive power and the dispersion are both weak, whilst in flint glass, on the other hand, both are very pronounced. As the specific gravity of flint glass is at the same time greater than that of crown glass, a fact due to the added lead, it was generally believed until lately, that the heavier the glass, the higher must be its refractive index, and vice versâ. By manufacturing different varieties of these two principal types, it became possible to arrange, between the lightest crown and the densest flint glass, a progressive, if incomplete, series ranging from the weakest to the most powerful refraction and dispersion (Fig. 9.) The dispersion was, however, in most cases, of a very uneven character, that is to say, the different kinds of glass produced spectra, the different parts of which were unequally extended. Although it had long been clear that the optician required a much more extensive series to choose from, the glass manufacturer could not be brought to place new products on the market. It is easy enough to understand this state of affairs when it is borne in mind that the amount of glass required for optical purposes was, and is, so insignificant in comparison with the total amount of glass used, that any enterprise in this direction did not seem to promise financially advantageous results. The opticians themselves had therefore to take the first step. And in this connection the name of the gifted Fraunhofer should be placed foremost among the precursors of Jena. Having been put upon the right track by the Franco-Swiss Guinand, Fraunhofer prosecuted his investigations with so much success that in all probability he would have solved the problem, if an untimely death had not put an end to his labours. Attempts were also made in England, but they did not lead to any result, and it may in consequence safely be said that at the time when Abbe first attacked the question of the improvement of the microscope, the technical position of optical glass-making was as low as it had been for generations.

During his investigations Abbe often found himself in a position to say that a highly efficient microscope could be constructed with such and such lenses, if they could be made of such and such glasses. Pairs of glasses characterised by a uniform dispersion in all parts of the spectrum would, for instance, have made it pos-

sible to obtain quite achromatic images by suitable lens combinations. Valuable results could also have been achieved with combinations of glasses having strong refracting and weak dispersing powers. These glasses were, however, unknown.

"For years"—so Abbe relates, speaking of his and Zeiss' work—"we carried on, in addition to our actual work, investigations of constructions of imaginary and non-existent glasses, and discussed the progress which might become possible if the producer of the raw glass could only be made to take an interest in higher optical problems." To test his views Abbe made experiments with liquid lenses, which could easily be so chosen as to have optical properties approximating to those of the glasses desired; experiments which were successful, but for easily understood reasons, could not find any practical application, and only strengthened the desire for the actual production of suitable glasses.

Otto Schott.

UNFORTUNATELY the manufacturers of optical glass were not interested in the higher problems: they continued, as hitherto, to make only such fluxes as could easily be melted, and they classified them according to weight, just as if they were intended for ships' ballast, as Abbe sarcastically remarked. But in spite of all this, the time devoted to the study of non-existent systems was not wasted; the desire to secure the actual realisation of results, at the time existing only in the imagination, grew greater and greater, and, as might have been expected, the problems themselves became more and more clear and comprehensible. And in the end the voice of the one who had so long cried in vain aroused an answering echo. A report on the state of microscopic optics, written by Abbe in 1876, on the occasion of an exhibition of scientific apparatus in London, in which he loudly bewailed the fact that the practical optician had at his disposal a fully-developed theory and thoroughly-tested practice — everything, in fact, except suitable glasses for the construction of the necessary lenses, led one of Abbe's readers to come forward and declare his willingness to undertake the work. This

was Dr. Otto Schott,* of Witten, in Westphalia, who, both by education and family tradition, had acquired a thorough knowledge of the glass industry. Keeping in mind the uncertainty of a successful issue and the probability that success, even if it should come, would not result in any great material advantage, one may safely assume that he was tempted to undertake the work solely by a desire to effect the solution of a problem repeatedly attacked in vain. Remembering this, one is justified in placing Schott on the same level as the two idealists, Zeiss and Abbe; even after it has been shown that the assumption of the improbability of material success was not justified, and that scientific glass manufacture was a much more profitable undertaking than could have been expected. It is not necessary that an idealist, in the best sense of the word, should renounce material success once and for ever; he who does so for a time only, harbouring idealistic thoughts which he is convinced will sooner or later become a reality, and who, when that has come to pass, enjoys the realisation of his long-deferred hopes, is in the highest degree an idealist. From this standpoint we are justified in concluding that the greatest idealist is at the same time the most successful practical man, and both Ernst Abbe and Otto Schott, each in his sphere, belong to this class.

Impelled by the reading of Abbe's report, Schott communicated with him in 1881, and together with him drew up a comprehensive scheme for the work to be undertaken. The first experimental meltings were carried out by Schott, at Witten, on a very small scale, 20 to 60 grams at a time, but including, as far as possible, all chemical elements which form vitreous compounds. The samples obtained were tested by Abbe, or by his assistant, Dr. Riedel, by means of a spectrometer (Fig. 8), specially designed for the purpose by Abbe. It very soon became possible to trace a certain relationship between the chemical composition of a glass and its optical properties, and this fact enabled the work to be carried on systematically. Schott removed to Jena in 1882, and, assisted by Carl Zeiss and Zeiss' son, Roderich, prosecuted his experiments on a larger scale. Perhaps, even then, it might not have been

*Otto Schott, born in 1851, at Witten, studied at Aix-la-Chapelle, Würzburg and Leipsic, from 1870 to 1875; took his degree at Leipsic with a dissertation dealing with the manufacture of window glass, and has since then been engaged in chemical works, some of which he started and organised in Spain and Scotland.

possible to carry the experiments far enough to permit of the beginning of regular industrial production, except for the aid afforded by a special grant from the Prussian Ministry of Education, at that time presided over by Herr von Gossler. The Ministry in question, influenced by the continued efforts of Abbe and of a number of Berlin scientists and technologists, among whom may be mentioned Carl Bamberg, Wilhelm Förster, and Wehrenpfennig, willingly gave a large sum for this particular purpose. This liberality is deserving of the highest praise, especially as the offer was not withdrawn in spite

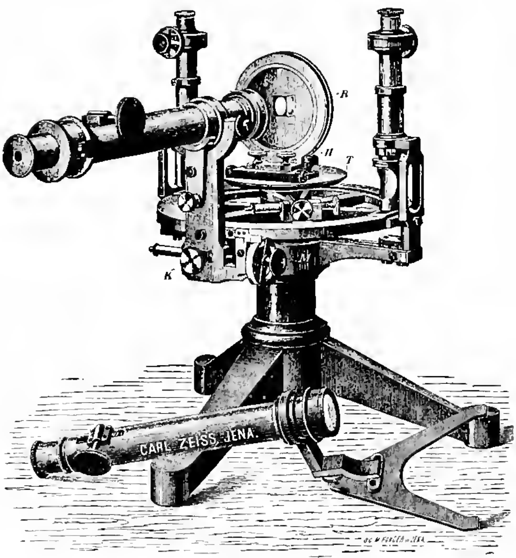


Fig. 8. Abbe's Spectrometer.

of Schott's refusal to accept the condition of removal to Berlin, a condition rejected by him because he did not wish to part company with Abbe and Jena. And if, looking backwards, we consider the course events would probably have taken if Schott had been tempted by the attractions of a large town to accept this condition, we cannot but feel intense satisfaction at the course of events. The co-operation of Abbe and Schott, their mutual influence and helpfulness had a most beneficial effect. To-day it is difficult to think of the Optical Works without the Glass Works, or vice versâ.

In the autumn of 1884 the Glass Works started operations under the name of "Glastechnisches Laboratorium Schott und Genossen,"

and as early as 1886 the first catalogue of glasses was published. It contained a large number of new varieties, especially Baryta, Borate, Phosphate and Zinc glasses, by means of which most of the requirements of the optician could be satisfied. Consequently we are justified in looking upon the publication of this price list as the beginning of a new era, not only for microscope construction, but for the construction of all kinds of optical apparatus.

It is impossible to give in this place a complete account of the commercial development of the Glass Works—some cursory

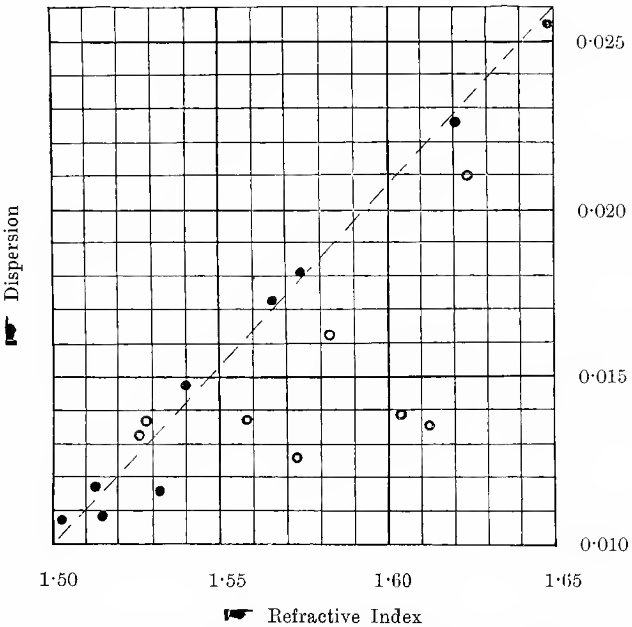


Fig. 9. Comparison of the old, (●), and the new (○), glasses. (In the old glasses the dispersion varies approximately as the refractive index).

remarks must suffice. Optical glass, so far as quantity is concerned, has long ceased to be the principal product of the Works, the greater part of the output now consisting of such articles as glass chimneys for lamps; glass for thermometers and other tubes; glass capable of resisting sudden and great variations of temperature for scientific instruments and the like. Nevertheless, the production of optical glass has not been neglected. The field of activity has, in fact, been latterly extended in various directions. Three problems in particular must be mentioned, two of which have already been solved,

while the third is nearing solution. All are concerned with the transparency of glass. The first has reference to the production of a glass which is colourless, according to a more exact interpretation of the term, that is to say, which transmits all rays of the spectrum in equal proportion. Ordinary crown-glass always has a greenish, flint-glass a yellowish tint, and even the earlier products of the Jena Works had more colour than was desirable for the purposes for which they were intended. Latterly, however, the Works have succeeded in producing certain kinds of borosilicate and baryta-glasses, which satisfy all the requirements, as to absence of colour, in the highest degree. The second problem, to the solution of which Dr. Zschimmer has considerably contributed, refers to the production of a glass which, without taking any account of its action on the visible rays of the spectrum, is distinguished by its relation to the rays which lie beyond the violet of the visible part of the spectrum, and which on that account are called ultra-violet rays. The old kinds of glass absorb the greater part of these rays, whilst the new kinds permit a comparatively large proportion of them to pass. They can therefore be used for many purposes—in photography, for instance, instead of the crystals, quartz and fluor spar, which have hitherto been used, and compared with which they possess many advantages besides that of cheapness. We shall again have occasion to refer to this subject when dealing with the astronomical department. The third problem concerns itself with the production of glasses with quite different optical properties, that is to say, coloured glasses. Coloured glasses, no doubt, exist in great variety, but the glasses we are here concerned with are those that transmit certain definite parts of the spectrum—one kind of glass one part and another kind of glass another part. The investigations which, as already stated, are not yet complete, promise to give glasses of great value for perfecting the photography of objects in natural colours.

The principal difficulties to be contended against in all such experiments as we have referred to, lies in the fact that the glasses produced possess, in addition to the qualities desired, others not so desirable. If the latter interfere seriously with the purpose for which the glass is intended it becomes necessary to get rid of them. One serious defect is the presence of striæ in the material; another, the existence of stresses in the glass, which may even cause it to burst. The latter defect can only be overcome by remelting the glass and cooling it in the most careful manner—oper-

ations which have been brought to a high degree of perfection at Jena. But besides the defects mentioned, there are others, which, although they militate against the appearance of the glass, from an æsthetic point of view, do not interfere with its optical value. The inclusion, for instance, of small air bubbles in the glass, whilst quite unavoidable under certain circumstances, does not in any way interfere with the performance of lenses used for astronomical, photographic, and many other purposes.

We have now reached the point where we must extend the scope of our inquiry to follow the extension of the operations of the Optical Works, which took place at about this time, and which was largely due to the possibilities which the possession of the new glasses gave birth to.

The history of the enterprise may be divided into three periods—a period of infancy, lasting from 1846 to 1872, which was ended by the realisation of Abbe's theory ; a period of maturity, which began in 1889 ; and between these dates, from 1872 to 1889, a period of transition characterised by (1) the development of the technique of the microscope (homogeneous immersion 1879, apro-chromatic objectives 1886, etc.), and (2) by the change from the method of production by individual workmen to the system of organised industrial production on a large scale. The increase of the business was a result of the increased perfection of the work done, and in its train followed the sub-division of labour, the starting of subsidiary departments for facilitating labour and, finally, the extension of the programme. (See appendix).

The Extension of the Scheme.

ALTHOUGH, as will be seen from the tables at the end of the book, the growing reputation of the microscopes made at Jena brought in course of time an increase of work, and with it an increase in the number of people employed, the character of the business remained very much the same during the first forty years of its existence. Towards the end of the seventies, however, everything changed at once. The workshop became a factory which, instead of producing microscopical apparatus only, soon embraced the whole field of practical optics, constantly

extending its operations in new directions. After Carl Zeiss had begun to show signs of age and decay, the work devolved more and more on Abbe alone. It became, under these circumstances, a matter of vital importance to find assistants who could either take an active share in the management, or who were fitted to become the heads of the various departments that were successively added to the business. Amongst the men who took an active part in making the place what it is, four are deserving of special mention.

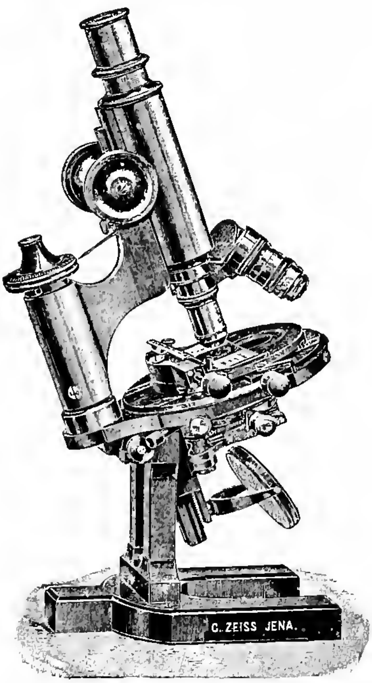


Fig. 10. Microscope Stand (1888-'90).

Roderich Zeiss, the son of the founder, placed the business on a sound commercial basis, and during the short time he was connected with it (he retired in 1889) assisted with great zeal in its technical development.

Siegfried Czapski,* on Helmholtz' advice, came to Jena when still very young, and by his ability and his ready grasp of the problems with which he was confronted, soon convinced Abbe, to whom he acted as assistant, that in him he had found the right man to take an active and independent share in the management of the enterprise. The manner in which Czapski has justified Abbe's confidence deserves the warmest praise, the more so as in many respects his position was an ungrateful one, and for this reason: Whilst those whose names we have, or will in the future, mention can be connected definitely with certain specific achievements and successes, in Czapski's case this can only be done in but few instances. And yet he has had a decisive share in almost everything which has made the reputation of Carl Zeiss what it is. That he was able to take such a part

*Siegfried Czapski, born in 1861 at Obra, in Posen, studied at Göttingen, Breslau and Berlin, where he took his degree with a thesis on a thermo-electrical subject suggested by Helmholtz.

was due not only to his clear mental grasp of the scientific principles involved in the solution of the problems with which he had to deal, which has *inter alia* enabled him to give the first comprehensive exposition of Abbe's geometric optics, or to his insight of the technical and administrative questions on which depended the carrying out of the problems, but largely, also to the amiable and genial manner with which he approached all concerned in the work.

Max Fischer, after having accumulated considerable experience at home and abroad, undertook, in 1890, the task of consolidating and extending the commercial side of the business; a task the difficulties of which, in the case of an enterprise developing at such a rapid rate are certainly not to be under-rated.

Rudolf Straubel, after the completion of his university course, first became an assistant at the Physical Institute of the University of Jena. He began to teach in 1893, and in 1897 was appointed a professor. His interest in Optics is doubtless traceable to the intimate friendship which, ever since his student days, has existed between him and Abbe. His writings relate chiefly to diffraction phenomena. Long before his accession to the staff of the Optical Works in 1901, he had become, to an ever-increasing extent, a confidant of the Firm. In 1903 he became a member of the Board of Management without, however, resigning his university position. This fact deserves to be specially mentioned, as it is a typical example of the intimate connection which has always existed between science and the enterprise. Besides Abbe and Straubel, another member of the Carl-Zeiss staff, Dr. Ambronn, is also a professor of the University

The Microscope Department.

WE must now consider a little more in detail those distinct departments of the establishment which have been developed since it became a large industrial concern. We shall take them in the following order:—

1.—The microscope department.

2.—The optical-projection and photomicrographic department.

3.—The photographic department.

4.—The astronomical department.

5.—The terrestrial-telescope department.

6.—The measuring-instrument department.

It is only right that we should start with the microscope department, from which the whole gigantic undertaking may be said to have sprung, and which is now under the supervision of Professor Ambronn and Dr. M. von. Rohr. We have already referred to the manner in which the fundamental problem of the determination of the ray-paths, taking diffraction into account, was solved. Leaving this then out of consideration, we must mention:—

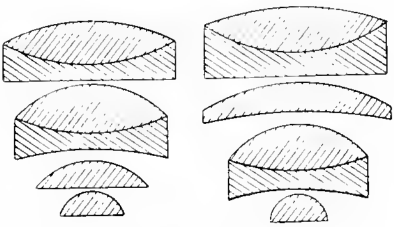


Fig. 11. Two forms of homogeneous-immersion objectives (4×).

1.—*The principle of homogeneous immersion.* The fact that rays of light in passing from the object, on the stage of a microscope, to the objective have to pass through two media — the cover-glass, which is indispensable for the protection of the object, and the layer of air between the cover-glass and the objective—always interferes with the formation of bright and sharply-defined images. It brings about loss of light, ill-defined images and reflection phenomena. These defects can be overcome by replacing the layer of air by a liquid, as water (Amici, 1840; Hartnack, 1855), glycerine (Gundlach, 1867), different kinds of oil (Amici, 1860), or, as Stephenson and Abbe proposed in 1878, by a liquid, the refractive index of which is the same as that of the glass employed for the cover-glass and for the front lens of the objective. The name "homogeneous immersion" was given to the system, in which optical continuity is thus ob-

tained, to distinguish it from the dry and from the ordinary immersion systems. Cedar oil, the liquid proposed by Abbe, is the one most often employed.

2.—*The apochromatic objective due to Abbe, 1886.* Although the dispersion due to refraction in the usual achromatic crown and flint glass systems is neutralised roughly, and to a first approximation, the secondary spectrum is not got rid of. We already know that to overcome this difficulty, we must have recourse to the new glasses. Some of the lens combinations containing the new glasses are called "new achromats," or, as the chromatic aberrations are practically neutralised in the eccentric parts of the image by the use of special compensating oculars, "apochromats."

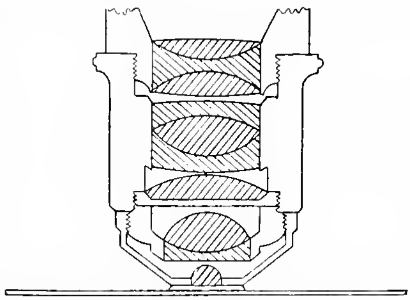


Fig. 12. Apochromatic objective ($2\frac{1}{2}\times$).

The image of a microscopic object, as seen through one of these

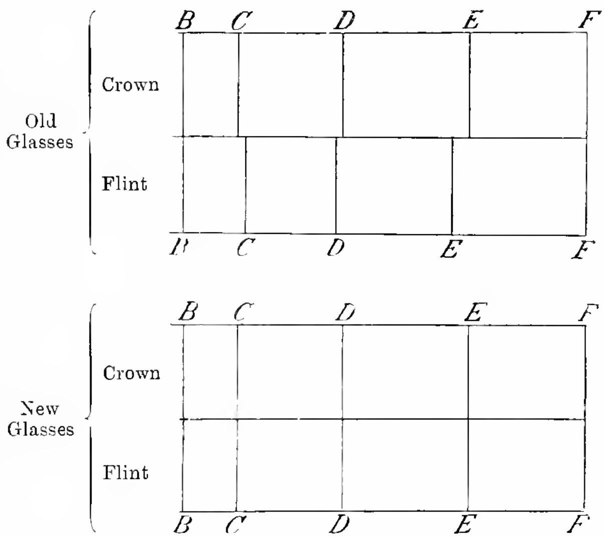


Fig. 13. The upper diagram shows the result of superposing spectra produced by a pair of old glasses—crown and flint, respectively. It will be noticed that although the Fraunhofer lines B and F coincide, the lines C, D and E do not. The lower diagram shows the result given by a properly selected pair of the new glasses. The coincidence throughout the spectrum, which is nearly perfect, results in the practical abolition of the secondary spectrum.

apochromatic homogeneous-immersion lenses, is brighter, better defined, and more true in colour than could at one time have even been hoped for. On the other hand these systems are very complicated, the objective alone, Fig. 12, consisting usually of

ten different lenses, some of them free and others cemented together.

Not all the lenses of these objectives are made of glass. Some are made of fluor-spar, a natural mineral which on account of its peculiar optical properties cannot very well be replaced by any other kind of glass. Fluor-spar is very common is nature, but much trouble and labour was needed to collect a sufficient quantity of satisfactory optical quality.

From the large number of other inventions to which reference might be made, we can only select:—

3.—*Abbe's condenser or illuminating apparatus*, already spoken of in an earlier chapter, which satisfies the highest demands which can be made on apparatus for illuminating microscopic objects.

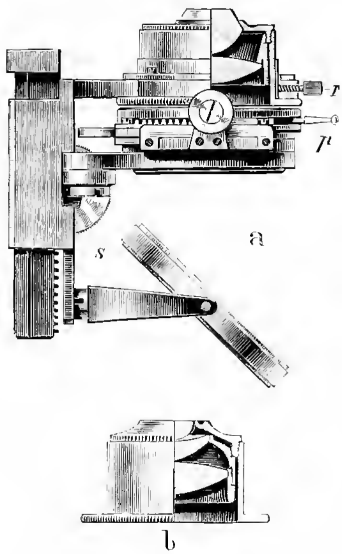


Fig. 14. Abbe's Condenser: *a* the two-lens, *b* the three-lens form.

4.—*Microscope stands*. A considerable improvement has been effected in the stand and stage, by means of which the fine adjustments of the body-tube, and the object on the stage, are effected with much greater accuracy, and at the same time in a way which does not interfere so much as hitherto with the examination of an extended object. Most of the credit for these improvements is due to Max Berger, who, since 1890, has been the head of the mechanical department of the establishment.

5.—*Binocular microscopes*. For critical observation, whether of a microscopic or telescopic character, monocular vision must always be the best. But there are cases in which it is advantageous to use both eyes, as for instance, when it is desired stereoscopically to observe distant objects. We shall see later on that the stereoscopic effect can be artificially increased. At present our object is somewhat different. We only intend to indicate how a microscope object, which appears as a flat surface when looked at with one eye, can be made to appear as a solid object when seen by two. This can be done in one of two ways. It may be done by the method employed in Abbe's stereoscopic eye-piece of 1881, which consists in dividing,

by means of a prism combination, each pencil of rays as it emerges from the objective, into two separate pencils, which then pass to different eye-pieces. If the whole of each pencil is effective in

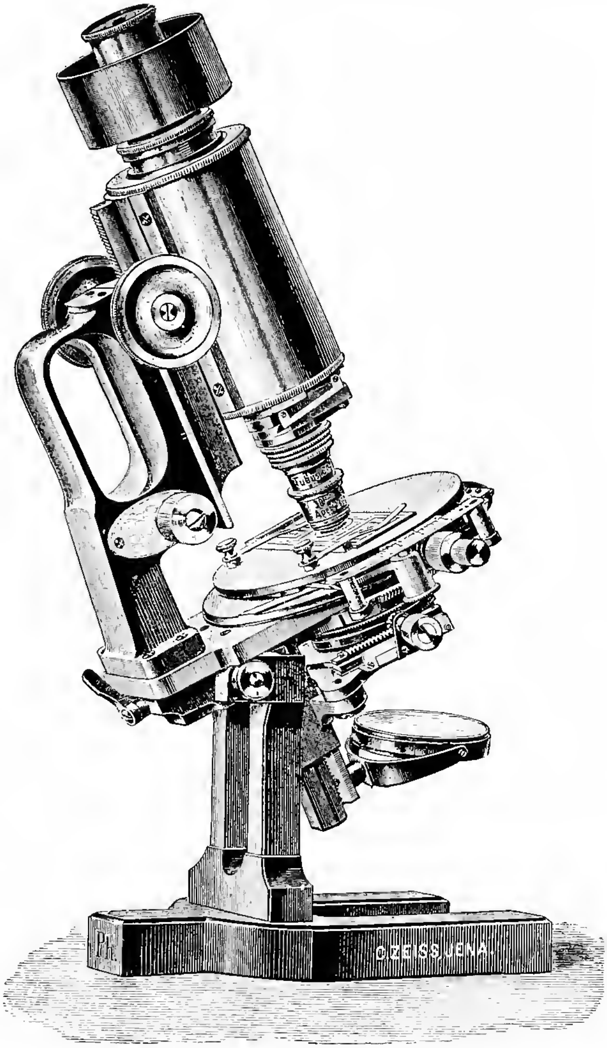


Fig. 15. The latest Microscope Stand: suitable also for photomicrography and projection.

the production of the final image, the ordinary effect follows; but if only one half of each is made use of, the other half being cut out by a semi-circular stop, the resulting image is stereoscopic. The second, and much more fundamental solution of the problem,

was first suggested by Greenough in 1892. In this case, Fig. 16, two complete microscope bodies are connected together in such a way that both eyes can be used at the same time. This is made possible by the use of a Porro-prism combination, of which we shall speak later. A real stereoscopic image is thus obtained. These microscopes are not of very great magnifying power, because, as already said, their chief object is to allow an estimate to be made of the actual shape of the object viewed.

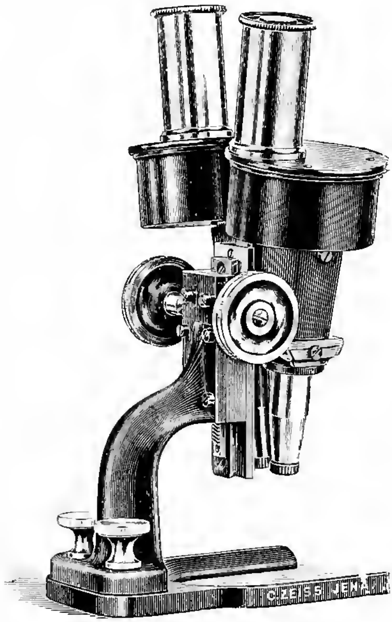


Fig. 16. Greenough's Binocular Microscope.

6.—*Auxiliary apparatus.* The department also produces a large number of small auxiliary apparatus, such as hand-magnifiers or lupes, drawing apparatus, Fig. 17, stands on which to place the prepared objects, counting and measuring instruments, devices for working with polarised light and others. Our space is too limited to do more than thus refer to them.

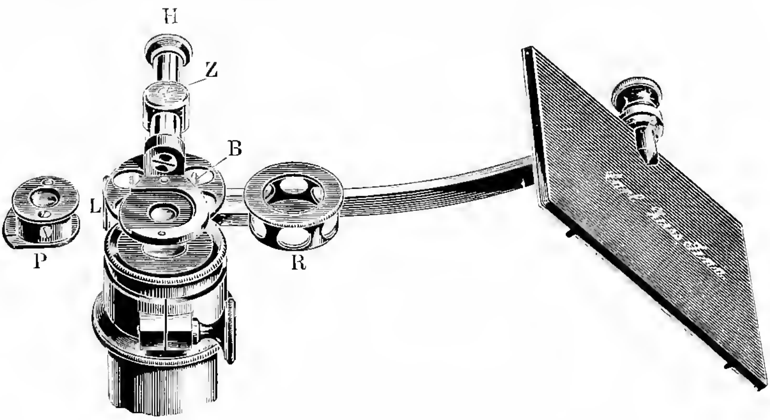


Fig. 17. Abbe's Drawing Apparatus.

But we must not close this chapter without calling attention to an interesting possession of the department. We mean the collection

of historical microscopes, formed under the supervision of Professor Ambronn. This collection contains representatives of all the different types of instruments introduced during the last 200 years, and is of great interest, not only to the scientist and technologist, but likewise to the historian, to whom each instrument represents a different period.

The Optical Projection and Photomicrographic Department.

THE heading of this chapter indicates that the subjects treated therein form a connecting link between microscopy and photography. The two problems with which we are concerned are:—(1) The projection of optical images on to a screen,

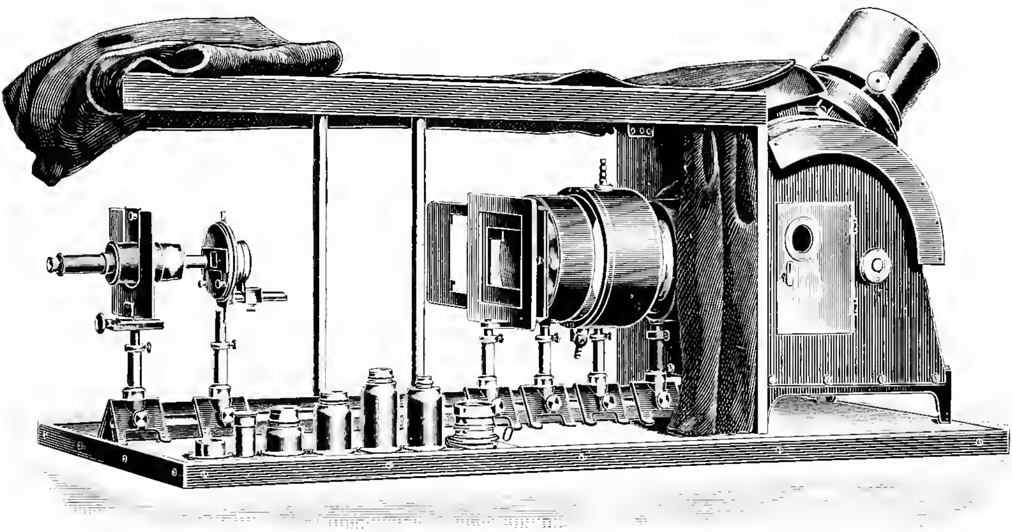


Fig. 18. Low-power Micro-Projection Apparatus.

and (2) the photographing of microscopic objects. Both have this much in common with ordinary photography: the images obtained are not directly, or subjectively, examined with the eye, but are first objectively produced on a surface, as a wall, a focussing or projection screen, there to be either examined with the eye, or chemically fixed. In apparatus employed for this purpose, the

ocular of the microscope is, therefore, done away with, or, if retained, it ceases to perform its original function, but being suitably modified, plays the part of a second objective. On the other hand, both optical projection and photomicrography have this in common with microscopy: the images obtained are larger, and not, as in ordinary photography, smaller than the original object.

The original impulse to the study of the problem of projection came from Roderich Zeiss, who recognised its importance for scien-

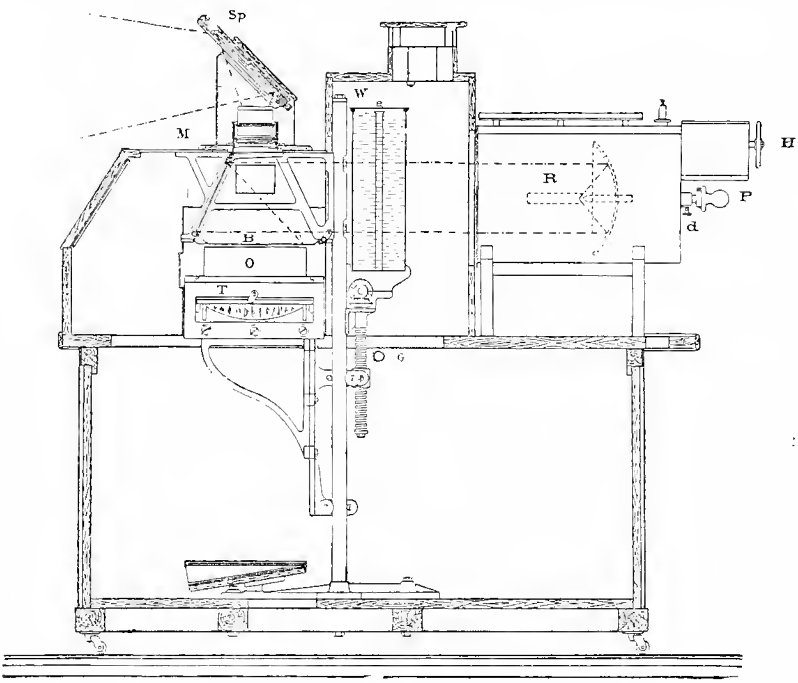


Fig. 19. Section of the Epidiascope.

tific purposes, as well as for elementary teaching. Since then so much progress has been made, and such great results obtained, that one would almost feel inclined to assert that no further progress were possible, were it not for the fear that facts might soon controvert such a statement.

To discuss in detail all the work done by the department now under the supervision of Dr. August Köhler is, of course, out of the question. But two points must be referred to. First the manner in which the apparatus has been adapted for the use of different and competing sources of light—such as the sun, the

lime-light, the electric-arc, and others. And secondly, the problem of the optical projection of the images of transparent and opaque bodies on to a screen; the first by means of transmitted light (diascopically), the second by means of reflected light (episcopically). The result of a long series of experiments was the construction of apparatus — the epidiascope (Figs. 19 and 20)— which is equally convenient for both purposes, and which gives

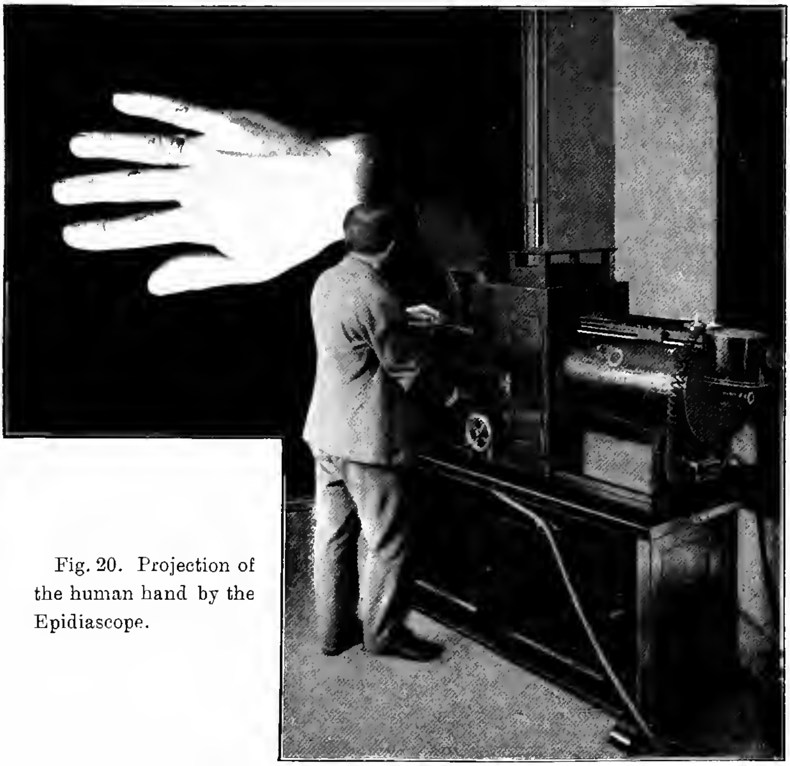


Fig. 20. Projection of the human hand by the Epidiascope.

results characterised by such sharp definition and true rendering of colour, as not to be easily forgotten when once seen.

The photomicrographic apparatus to which we now pass, consists of illuminating apparatus, a microscope system, and a camera; the whole being capable of either horizontal or vertical adjustment and use. It only remains now to give some particulars of the larger and smaller patterns (Fig. 21). One point of importance in connection with photomicrography must, however, still be explained. The layman to whom photomicrography is mentioned, naturally considers its object to be limited to the reproduction of the objects

seen in the microscope, and looks upon it only as a means for enabling the student again to study the object, to reproduce it for other students, it may be after the original object has ceased to exist. It will not strike him that it may be possible to see on the photomicrographic plate details which cannot be seen in direct microscopic vision, and yet such is the case. We know already from what has been said when speaking of the microscope, that the assumption that light consists of rays, is not exact enough for modern practical optics. Rays are postulated for the sake of simplicity, but what we have really to take account of are waves of

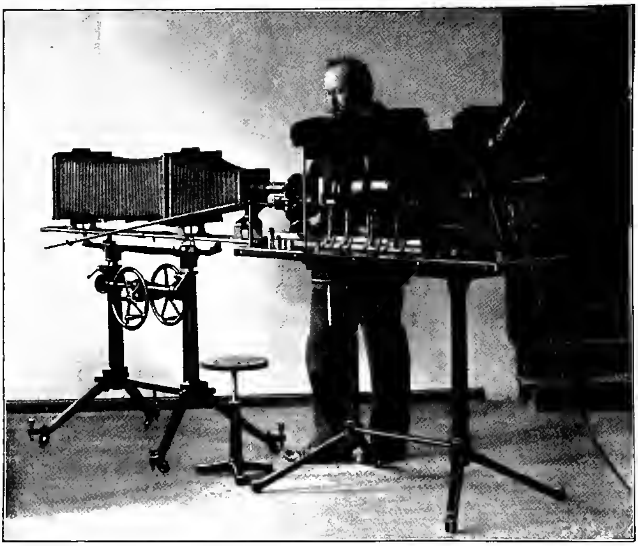


Fig. 21. Photomicrographic Apparatus.

infinitesimal and different lengths, which constitute the different kinds of light we call colour. The useful magnification of an object is limited by the fact that when the size of the part to be differentiated is so small as to be equal to the wave-length of the light employed, confusion ensues as the result of diffraction and interference; consequently the smaller the waves, the smaller the parts of the photographed object, which can be differentiated. That this is so becomes intelligible by a consideration of the principle on which the screens—glass plates ruled in squares—now so much employed in modern reproduction processes are based; the smaller the square, the more minute the detail, which can be reproduced in the image. Consequently the object aimed at is the

reproduction of microscopic images by means of light of as small a wave-length as possible. Blue light gives better results than red, but light exists of still smaller wave-length than blue or violet—ultra-violet light—to which the eye is not, but to which the photographic plate is sensitive. This light therefore not only perpetuates our observations, but acts as a means for indirectly extending the range of the eye.

Lately, Dr. Siedentopf, a scientific collaborator at the Optical Works, and Dr. Zsigmondy, following a path first pointed out by Abbe, have independently of him, worked out a method of rendering visible very small particles of matter, such for instance, as gold particles in colloidal solutions, although the size of these particles

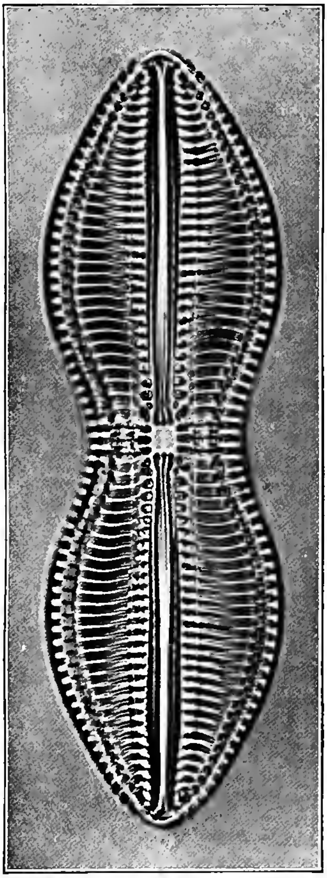


Fig. 22. Navicula crabo (500 ×).

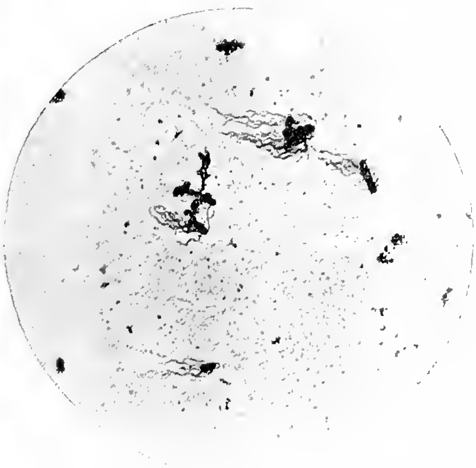


Fig. 23. Typhus bacilli (1000 ×).

is below the limit of the resolving power of the microscope, as determined by Helmholtz and Abbe. The gold particles themselves are too small to be seen, but their diffraction discs are made visible by being brilliantly illuminated against a very dark background.

How this is done is shown by Fig. 24. The object is laterally illuminated by means of a very complicated optical system, so that

the light does not pass directly into the microscope. It is impossible to go into details, but we may state that the method can be applied to render visible the light effects of particles the linear dimensions of which are between the limits of a 6-millionth and

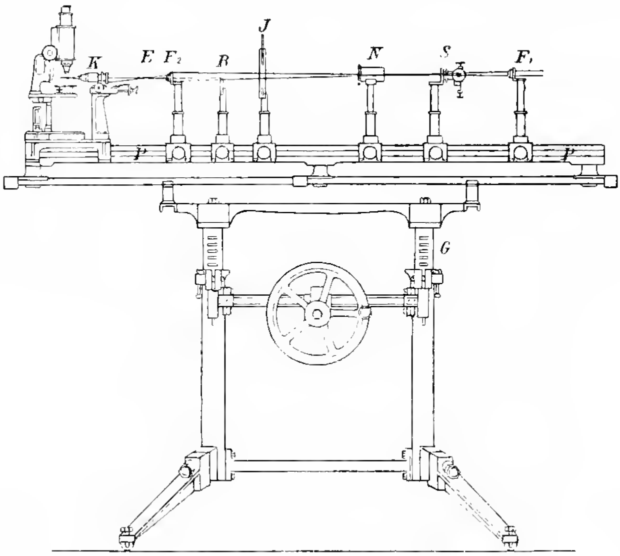


Fig. 24. Ultramicroscope.

a 250-millionth of a millimeter. Although these "ultramicroscopes" have been placed on the market for scarcely a year, biologists and medical men have already achieved great results by their aid, to which fact the very large demand that has arisen for these instruments is undoubtedly to be attributed.

The Photographic Department.

AS soon as Abbe and Schott found themselves in possession of the new glasses, they naturally wished to see other branches of practical optics besides microscopy benefited by their application; and this wish became the more pronounced the more clearly Abbe recognised the necessity of emancipating himself from dependence on a single article of manufacture. It was for this reason that the Optical Works took up the subject of photography. The time for so doing could not have been more fortunately chosen; it was just then that photography, ceasing to be the monopoly of the professional, permanently established itself in the laboratory of the student and the home of the amateur, and thus added two new and extensive fields to its domain.

Paul Rudolph entered the mathematical department of the Optical Works in 1886. After having practised microscope and telescope calculations for some time, he was selected by Abbe as his assistant in working out a photographic system which had for some considerable time occupied his attention. These labours resulted in the taking out of a patent, which need not, however, be considered, as it was shortly afterwards superseded by other systems that were entirely due to Rudolph.

Rudolph undertook the task of designing a system which should not only eliminate the errors of spherical aberration, naturally inherent in lenses with spherical surfaces, but should also rectify an objectionable characteristic of every uncorrected system—the imaging of an object-point off the axis by a line or cross—and should thus satisfy, at least in one direction, the highest theoretical requirements, and reproduce each object-point as a point in the image. The error thus rectified being known as "astigmatism," the name anastigmat was given to the new system. The name "stigmat" would have been more concise, and as the two negatives in "anastigmat" cancel one another, its meaning would have been the same. In making his calculations, Rudolph left entirely out of account, until near the close of his labours, the chromatic aberration, the elimination of which was formerly the first task undertaken by the designer of an optical system, and then sought to eliminate the error by recourse to the great variety of new glasses at his disposal. The method he adopted has led to the most satisfactory results.

The new objectives, produced in 1890, realise the principle of

the opposite or opposed gradation of the refractive indices in the front and back lenses. The front lens, which is the element relied upon for the correction of the spherical aberration, is made up of crown glass of a low, and flint glass of a high refractive index (old glasses), whilst the back lens, the element relied upon for the anastigmatic flattening of the field, is made up of crown glass of a high, and flint glass of a low refractive index (new glasses). Finally the correction of the chromatic aberration is brought about by the reciprocal or opposed action of the two lenses. The double anastigmat, which was made in two forms—two plus two, and two plus three lenses—was succeeded in 1893 by the triple cemented, and in 1894 by the quadruple cemented anastigmatic single objective, which could also be used as a member of a double anastigmat or of a satz-anastigmat. Figs. 25 and 26 represent

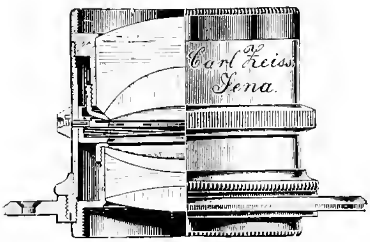


Fig. 25. The Protar Photo-lens.

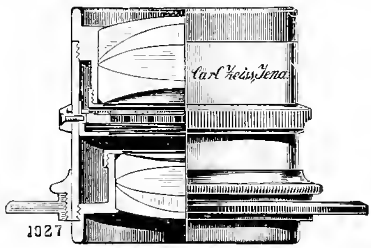


Fig. 26. The Double Protar Photo-lens.

these constructions. The anastigmat, now called the "Protar," to distinguish it from the imitations and similar constructions of other firms, was soon in great demand in photographic circles, especially amongst amateurs. In a little over a decade quite 100,000 anastigmats have been sold by Zeiss and by firms manufacturing under license.

Rudolph, unwilling to rest on his laurels, proceeded with his investigations, and has lately been successful in placing upon the market some objectives that already occupy a high position amongst the many good objectives now available for photographic purposes. They are either specially adapted to serve particular and limited purposes, or designed for general all-round work with the object of making it unnecessary for the amateur, for whom they are principally intended, to buy a complete set of objectives. Among these general objectives we may mention the "Unar" (1899), Figs. 27 and 28, which can be used for almost any purpose, and which, in consequence of its comparatively simple construction, is sold at a

correspondingly low price. The "Planar," on the other hand, belongs to the class of special objectives. When of short focal length it is well adapted for instantaneous photography, for enlarging and reducing pictures, and for projection apparatus; when of greater focal length it is unsurpassed for all kinds of photo-mechanical reproduction processes (Fig. 29 and 30). The latest system placed on the market is the "Tessar" (1902), which, whilst of simpler construction than the "Unar," gives superior results. It works, however, at a smaller aperture (Fig 31). Mention must be made of the telephoto-objectives intended for taking large-size pictures of distant terrestrial objects (Fig. 32), and of the systems adapted for use in the various photo-mechanical reproduction processes.

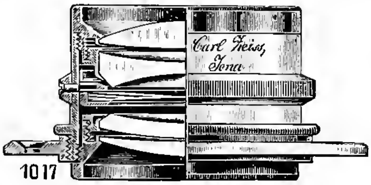


Fig. 27. The Unar Photo-lens.

Finally, as a curiosity, and by way of contrast, we must mention the "Anamorphot," an objective specially constructed for producing a distorted image, a result which it is the aim of most objectives to avoid. Of course, the distortion takes place in a

Fig. 28. Photograph taken with the Unar Photo-lens.

manner determined beforehand. The system is made up, not of spherical, but of cylindrical lenses. Besides being employed for

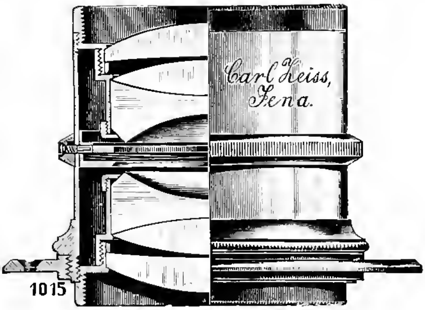


Fig. 29. The Planar Photo-lens.

the production of comical distorted pictures, it may also be used for more serious purposes, such as the production of new patterns

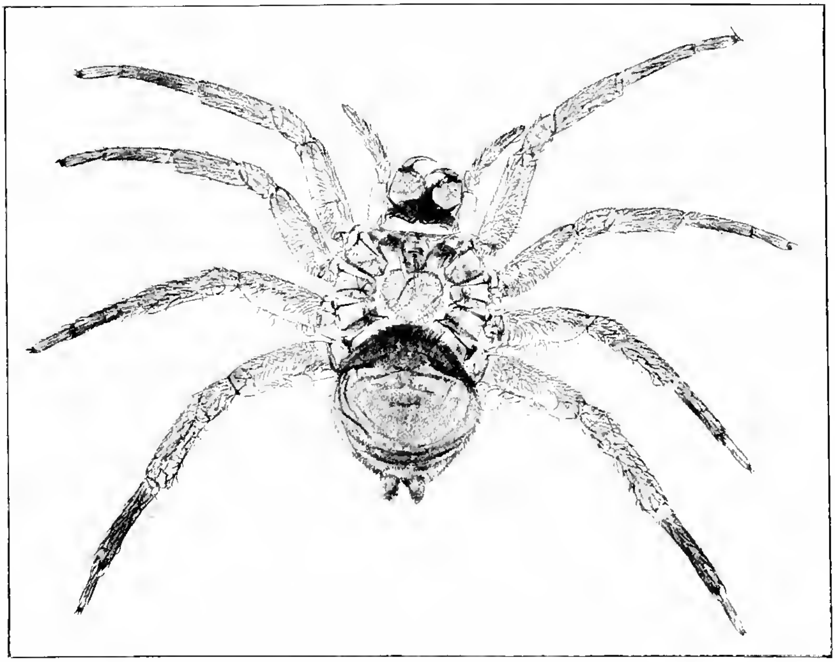


Fig. 30. Spider taken with a Planar Lens and the Photomicrographic Apparatus.

by the proportionate lengthening or widening of textile and other designs, or by changing the rectangular arrangement of such designs into an oblique one (Fig. 33).

The subject dealt with in this chapter is exhaustively treated in a book on the "Theory and History of the Photographic Objective," by Moritz von Rohr, formerly scientific collaborator in the photographic department, and at present engaged as theorist of the microscope department, to which book readers interested in the subject are referred.

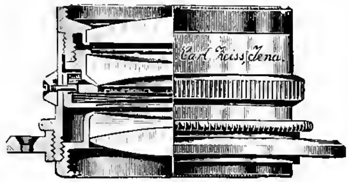


Fig. 31. The Tessar Photo-lens.

For some time past photographic shutters for time and instantaneous exposures have been manufactured at Jena, to which, since the purchase of the "Palmos" camera factory, cameras, especially those of the hand type, for plates and films (Figs. 34 and 35), as well as photographic enlarging apparatus have been added.

The latest production of the Works, of which a description must

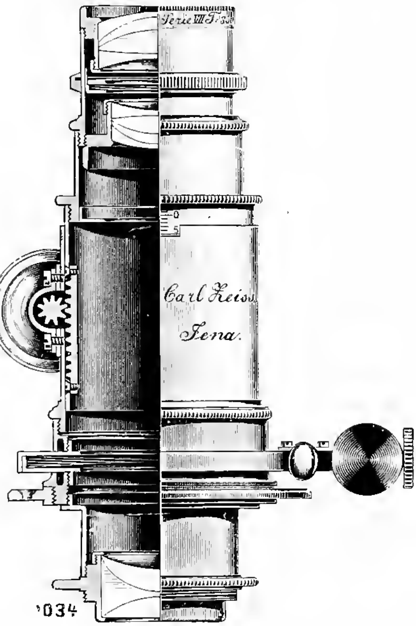


Fig. 32. Tele-photo Lens.

be given, is the Verant, an instrument by means of which an observer is enabled to view photographs correctly. The calculations on which it is based were made by Dr. M. von Rohr. We are dealing here with a subject about which even the educated have very

hazy notions. That natural objects can be seen in relief, that is to say, not flat, but as having depth, is practically due to the fact of binocular vision. It is true that as the result of practice and

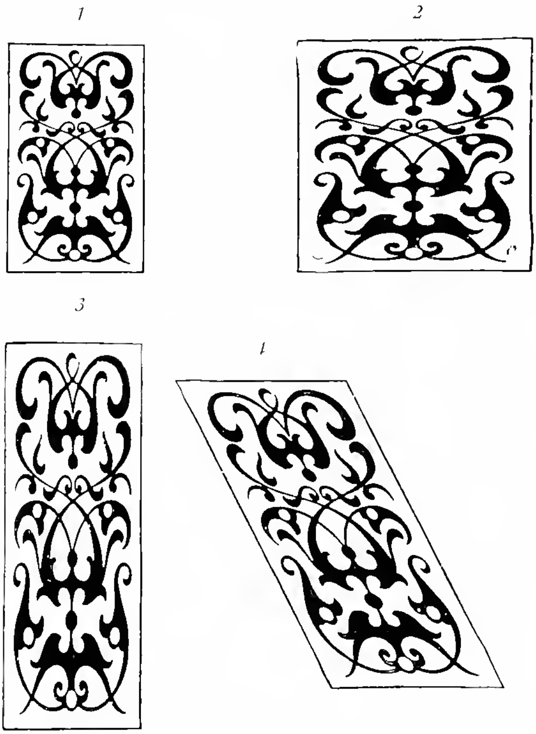


Fig. 33. Anarmorphosis: The original 1 is shown at 2 laterally distorted, at 3 longitudinally distorted, and at 4 obliquely distorted.

experience we become able to see objects in space in relief, with only one eye, but this is more the result of a mental process than of an act of actual vision. In looking at the pictorial representa-

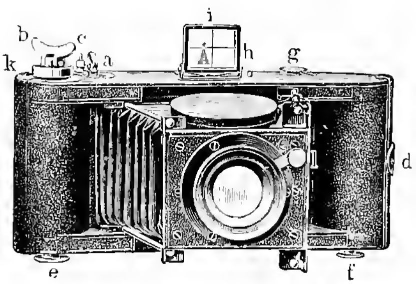


Fig. 34. The Film Palmos Camera.

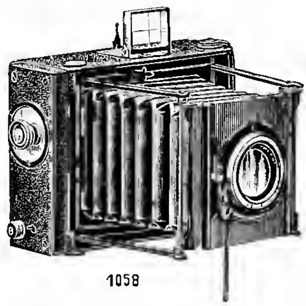


Fig. 35. Small Palmos Camera.

tion of a natural object, it is of course physically impossible to see the picture in relief, neither is it possible, so long as both eyes are used, to do so mentally, because the fact that the picture is actually seen as a flat surface makes it impossible for the psychical conditions necessary to impress us with the appearance of solidity to arise, consequently only one eye should be used. But even in this case the necessary conditions will only be satisfied when the point of view from which the picture is observed is identical with that from which it was taken. This is the reason why those who are in the habit of looking at paintings, close, or still better, cover one eye, and view the painting with the other through a short

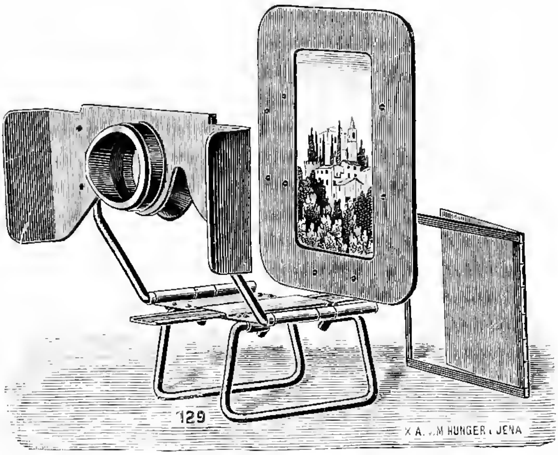


Fig. 36. The Verant.

tube, after having placed themselves at the proper distance. When dealing with photographs, taken with a lens of given focal length, it is obviously possible to realise the necessary conditions for correct viewing by the employment of a frame on which the picture and the apparatus for viewing it are suitably mounted.

Whilst in most cases the Verant (Fig 36), is nothing more than a convenient instrument which saves the observer the trouble of having to search carefully for the best position from which to view a picture, it becomes almost indispensable for viewing the small photographs taken by amateurs in which, in consequence of the short focal distance, the point from which they ought to be viewed is so close to the photographs that it becomes impossible to see them clearly with the naked eye. But the effect of the Verant is really astonishing in the case of photographs suffering from some of

the usual defects, whether intentionally or unintentionally produced, such, for instance, as convergence of the vertical lines, want of proportion between fore and background, and the like: the distortion is corrected in all such cases.

Stereoscopic pictures to be viewed simultaneously with both eyes evidently present a similar problem. The "Double Verant," an instrument that solves the problem, will shortly be at the disposal of all interested in the subject.

The Astronomical Department.

IN the following chapters we shall deviate somewhat from the historical sequence of events in the Zeiss Works, and deal with the astronomical type of telescope before devoting our attention to the terrestrial type. We do so because the latter, when compared with the former, is, in consequence of the fact that it must show an erect image, of more complex construction. In the astronomical telescope and in the microscope, on the other hand, it is not of any importance that the image should be erect, because the orientation of the object is not of much consequence. Therefore, when discussing the terrestrial telescope in the next chapter, we shall concern ourselves principally with the devices by means of which the image is made to appear erect, or in its rigbt position.

The astronomical department is the youngest of all. It is true that the success of the new glasses in other branches of optics had directed attention to this branch also, but the difficulties to be surmounted were very great. In the first place it must be remembered that the manufacture of astronomical instruments is attended by great risks. The work requires very extensive plant, whilst the orders which have to be executed are, in the very nature of things, few and are therefore only individually important. The value of a large astronomical instrument amounts to many thousands of pounds. Moreover, each order represents a separate problem, which makes the calculations difficult, and results, in many cases, in a financial loss. And, finally, the few firms already engaged in this class of work had acquired such a firm hold on the

favour of the public, that success could only be looked for by the production of something really superior.

To turn out better work was, at the time of which we are speaking, easy enough, and is so still; a statement which refers not only

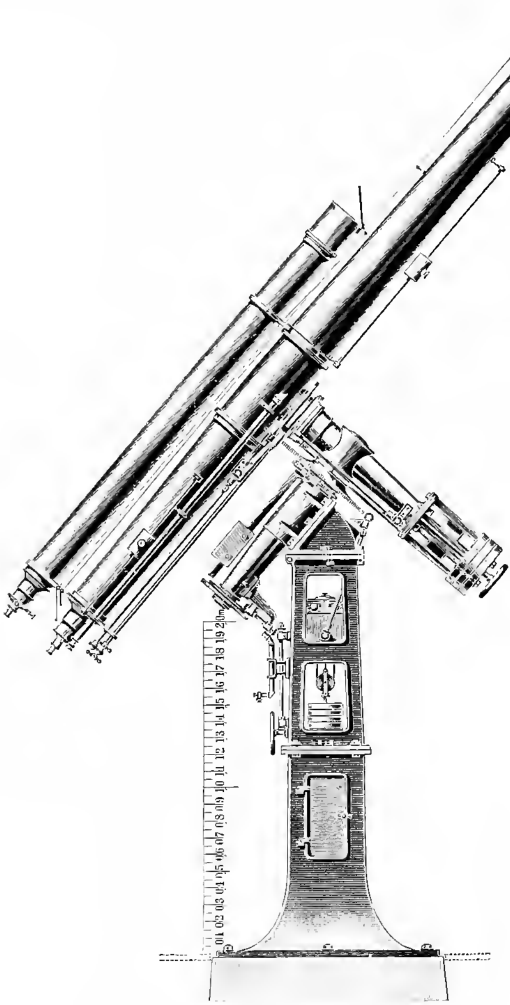


Fig. 37. Equatorially-mounted Telescope.

to the strictly optical work involved, but quite as much to the mechanical construction of the instruments. The necessity for better work carried with it the necessity for having someone of the first rank to put in charge of it, a matter by no means easy, considering the limited choice. Dr. Albert König is responsible for

the optical work involved in the calculations required. As far as the practical side of the question is concerned, there occurred in 1897, the opportunity of engaging a man of the necessary qualifications and ability, in the person of Dr. Max Pauly, who until then had been engaged in quite a different sphere. Interested in the subject, however, he devoted his leisure successfully to the construction of telescope lenses. In the year just mentioned, then, Dr. Pauly resigned his occupation, and taking up his residence at Jena, undertook the direction of the newly-founded astronomical department; Dr. Villiger acting as his assistant in the purely astronomical part of the work. For the mechanical department, too, a very capable man has since been engaged, in the person of the engineer, Mr. Franz Meyer.

Fig. 38. Mounting a Telescope.

Instruments of any desired size and quality can be made. The circumstance that the Glass Works, where the raw material is converted into telescope lenses of the most gigantic dimensions, are in the immediate vicinity of the Optical Works, is a factor not lightly to be left out of account. Formerly such lenses had to be imported from France or England, but for some years past they have been made by a much improved process at Jena. The rough grinding and polishing of these lenses is effected at the Glass Works, so that the skilled labour required for the mathematically-accurate polishing can be begun immediately they are delivered at the Optical Works.

The Jena objective represents, from more than one point of view, a considerable advance on those made elsewhere. The first problem attacked, and successfully solved, was the abolition of the secondary spectrum; following this, spherical aberration was likewise eliminated to a very large extent, and finally it became pos-

sible to realise a long-desired object, and to eliminate both errors simultaneously in one and the same objective.

It has further become possible, as a result of the production of glass which possesses a much greater transparency for ultra-violet, or photographically-active light, to make telescope objectives which mark an epoch in the history of astronomical instruments for photographic purposes. To become convinced of this fact it is only necessary to compare two photographs of the same celestial view, one taken with an old, and the other with a new objective, to see how much more detail is rendered by the new

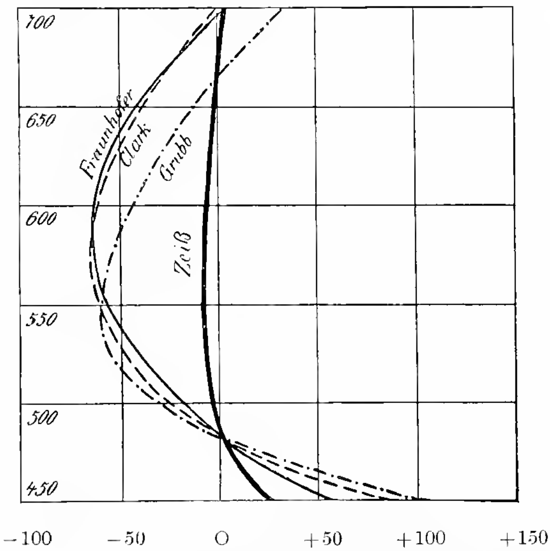


Fig. 39. Diagram showing the variations in the focal lengths of different telescope objectives for different wavelengths of light.

objective. Reflecting telescopes, which for a long time past have been practically neglected, have latterly again begun to attract attention at Jena. The object has been, of course, to overcome the defects to the presence of which the neglect of this instrument was originally due. Dr Schupman suggested a very radical and original method of overcoming the difficulties when he proposed that the rays of light should be laterally reflected, but neither Schupman himself, nor the Optical Works which, under Abbe's personal supervision, occupied themselves with the solution of this problem, were able to overcome the difficulties, and the idea of achieving success in the way proposed had to be abandoned.

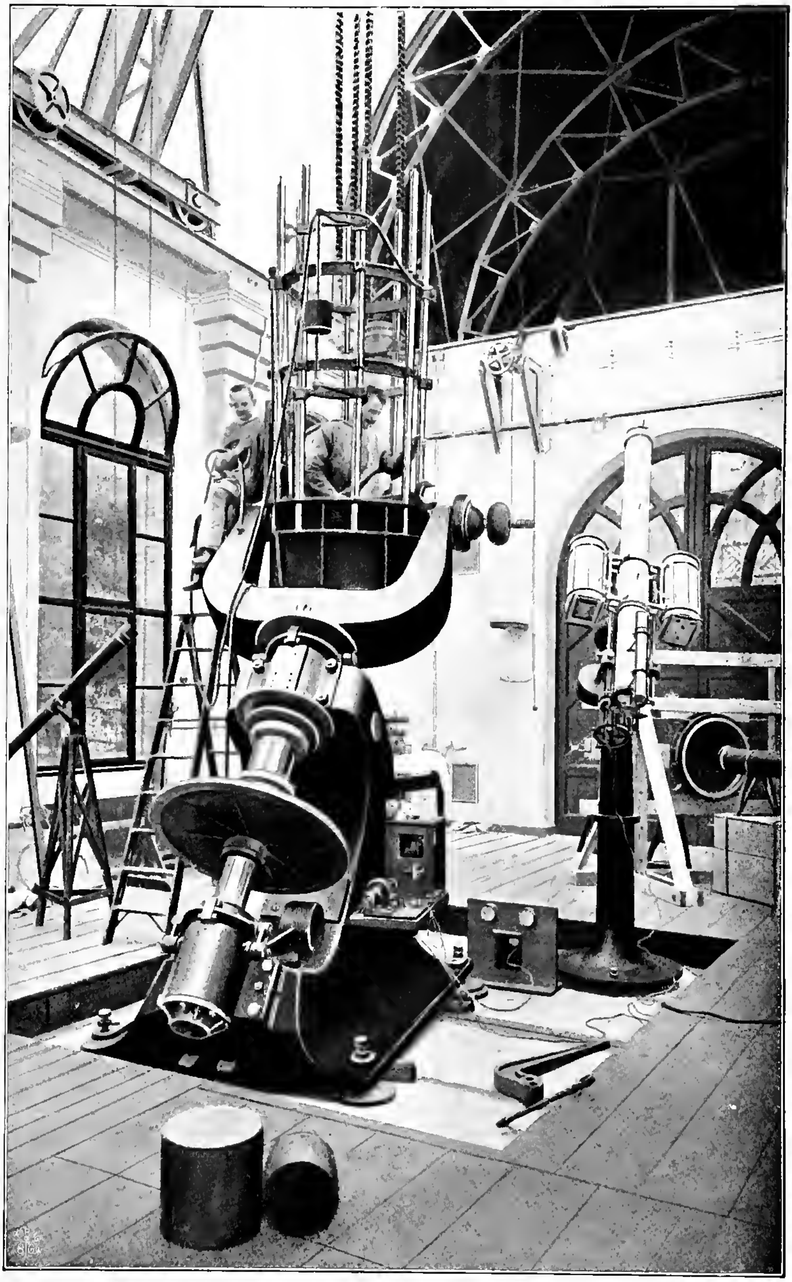


Fig. 40. Erecting Shop.

On the other hand, the attempts to improve the old reflecting telescopes by the more accurate grinding of parabolic reflecting surfaces became more and more successful. The difficulties of the task will be appreciated when it is remembered that the thickness to be removed from the surface of a mirror amounts, in many cases, to not more than a fraction of the thousandth part of a millimeter.

The mechanical construction of the telescope, too, provides a large number of still unsolved problems. It is still, for instance, an open question as to whether it is better to make use of closed tubes, or whether an open framework is the more suitable. In the latter case the temperature of the air can much more easily equalise itself, whilst, on the other hand, the former construction appears much more substantial and rigid. The adjustment of such telescopes, too, not to speak of many other problems, is undoubtedly open to improvement.

The first catalogue of astronomical objectives, either of old or of Jena glass, was published in 1899. It related to objectives for direct visual observation, as well as for photographic purposes, and included oculars and auxiliary fittings for the same. The first catalogue of mountings for telescopes was published in 1902.

To cope with the work of the new astronomical department it was found necessary, in addition to increasing the ordinary workshop accommodation, to erect two large and separate buildings. A large erecting shop, of new construction and design, shown in Fig. 40, has been built. The figure shows the parts of a reflecting telescope of large dimensions being assembled, whilst a little to the right a small equatorially-mounted telescope can be seen. Further, an observatory has been built on the plateau of the Forstberg, 150 meters above the valley of the river Saale. At the present time, therefore, the astronomical department of the Optical Works need not fear competition. It can supply instruments of any desired size, and of the most perfect workmanship.

The Terrestrial-Telescope Department.

COMING now to the consideration of the terrestrial telescope, we again enter a field into which it was Jena's good fortune to be able to introduce a surprising novelty at a time when it might have been thought that the market was already fully supplied, and in which the demand had been stationary for a considerable period. It must, however, be admitted that it was a field in which a large number of people were interested, since articles such as opera-glasses, field-glasses, and terrestrial telescopes of the ordinary forms are used generally by the public, even if special types of them appeal more to the expert. To be able to understand clearly the importance of the improvement made at Jena, it becomes necessary to go somewhat into details.

The image given by a terrestrial telescope must appear right-side-up, and without lateral inversion, that is, as the object is seen by the eye direct. Such a result can be obtained by two different methods—one direct and the other indirect. The first, or direct method, is the one adopted in the Dutch or Galilean telescope; the second, or indirect method, is the one adopted in the so-called terrestrial telescope. Each of these types has inherent advantages. The Galilean telescope consists of two simple optical elements only—a positive lens acting as an objective, and a negative lens as an eye-piece—consequently its construction is simple, its length not great, and its weight small: On the other hand, it gives a defective image, and the field of view is small and of unequal brightness. These defects are of little importance so long as the magnifying power does not exceed $1\frac{1}{2}$ to 3 diameters, but they increase rapidly in importance with the increase of magnifying power. In practice, therefore, this construction is only adopted for instruments of low magnifying power, such as opera-glasses, field-glasses and the like. The terrestrial telescope, fitted with a separate erecting system of lenses, does not suffer from the same defects; its field of view is large and of uniform brightness, and the image is sharply defined; but to detract from these advantages, its length must be equal to the sum of the focal lengths of the objective and the eye-piece, to which must be added the length necessitated by the erecting system of lenses. In the Galilean telescope, on the other hand, the length is equal, simply, to the difference of the focal lengths of the objective and the eye-piece.

The terrestrial type thus becomes both long and heavy, and the longer and heavier it is, the lower its magnifying power. In practice, all such instruments, therefore, are of great magnifying power—12 diameters or more—because in instruments of low magnifying power the body would be too long for convenient handling. The question naturally arose then, whether it was not possible to construct short instruments of the terrestrial, or erecting type,

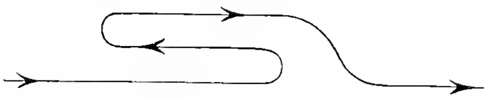


Fig. 41. Bent Wire.

of a magnifying power of from 4 to 12 diameters. The problem at first sight, perhaps, appears insoluble, but a simple analogy suggests that it might be solved, at any rate, theoretically. Is it necessary that the ends of a piece of wire one meter long should be one meter apart? Certainly not! The wire may be bent in different ways, and, as shown by Fig. 41, the last piece may form a continuation of the first. And now to apply this illustration to

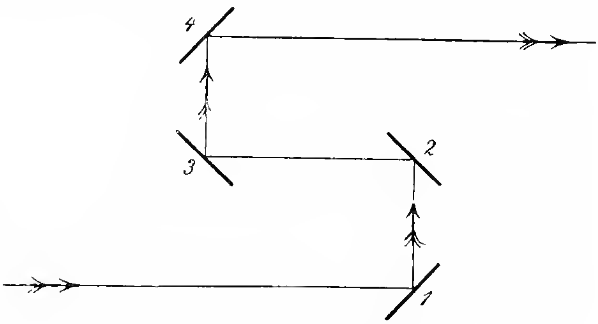
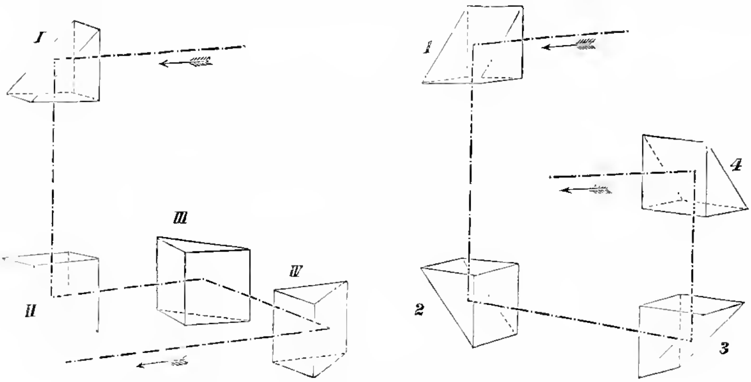


Fig. 42. A Reflecting System.

our problem: The erecting of the image, instead of being brought about by refraction through lenses, may be effected by reflecting surfaces, which cause the rays, Fig. 42, to be turned back upon themselves. For image-forming purposes all the parts of the path of the ray, whether they run forward or backward, are added together; for determining the length of the instrument different parts may cancel each other. Thus the optical length may be very much greater than the physical length. It was found that reflection by ordinary silvered-glass mirrors was not practicable; thus it became necessary to use total-reflecting prisms in which the light is reflected in glass, at a bounding

surface between air and glass. If the resulting image is to appear right-side-up, and without lateral inversion, and if the rays on emergence are to run in the same direction as that by which they enter the combination, it will be found that four such prisms



Figs. 43 and 44. Path of a ray in a Porro-prism System.

are required. Two combinations which satisfy these requirements, and the path of the rays through them, are illustrated in Figs. 43 and 44.*

The illustrations show that whilst the path of the emergent ray

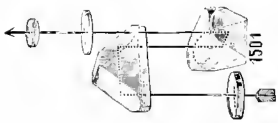


Fig. 45. The Optical System of a Field-glass.

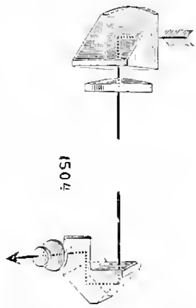


Fig. 46. The Optical System of a Stereo-telescope.

lies in the same direction as that of the incident ray, it is not in continuation of it, but is laterally displaced; consequently the telescope is unsymmetrical, and the problem, at first, appears to have been incompletely solved. Fortunately, however, our prism

*It is interesting to know that Abbe had constructed about the year 1875, that is long before his invention was known, a terrestrial telescope fitted with these prisms.

combination in this respect is like Mephistopheles, who desiring evil, always actually effects good. The history of inventions cannot, however, show many cases in which an original defect led, not only to an unexpected but to a valuable result.

Fig. 47. Sporting and Marine Glass.

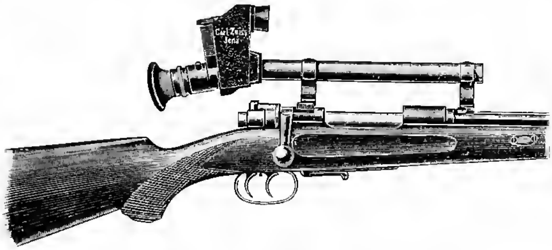


Fig. 48. Sighting Telescope for Rifles.

Two advantages were obtained by this lateral displacement. In monocular instruments it allowed the user to "see round the corner." If the distance between the individual members of the prism system is small, the lateral displacement of the ray will likewise be small; but by increasing the distance between the prisms, the displacement can be made as great as desired. The diagram, Fig. 46, and

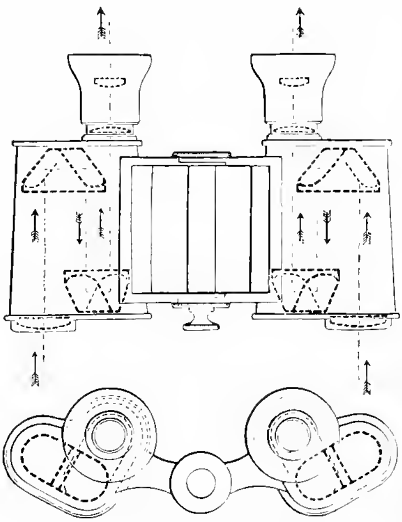


Fig. 49. Diagrammatic elevation and plan of a Prismatic Field-glass.

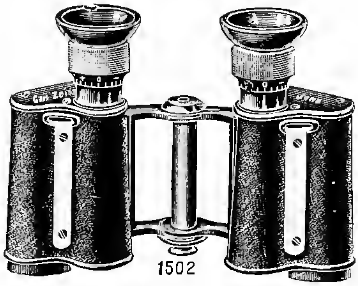


Fig. 50. Prismatic Field-glass.

the illustrations of the complete instrument, Figs. 52 and 53, show clearly how the user is able to look over a wall, for instance—a great advantage in some cases. Fig. 47 illustrates a

monocular marine glass, with two interchangeable oculars, giving magnifying powers of 5 and 10 diameters. The telescopic rifle sights for sporting and military purposes (illustrated in Fig. 48), which have lately become so popular, belong to this class. The second advantage is realised in addition to that first mentioned by

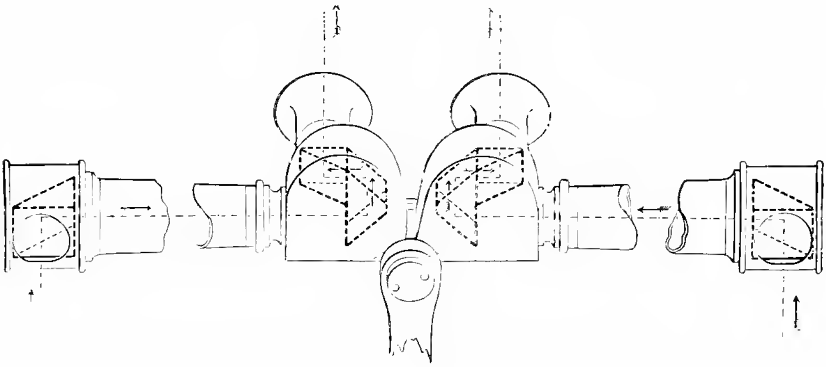


Fig. 51. Diagrammatic view of a Stereo-telescope.

binocular instruments, such as field-glasses. If only for æsthetic reasons, the two tubes of these instruments would probably be so arranged with respect to each other as to cause the lateral displacements of the rays to occur symmetrically, as indicated in Fig. 49. In this case, the inter-objective distance becomes greater than the inter-ocular distance, and if it be remembered that the stereoscopic effect resulting in the perception of depth in the observed images,

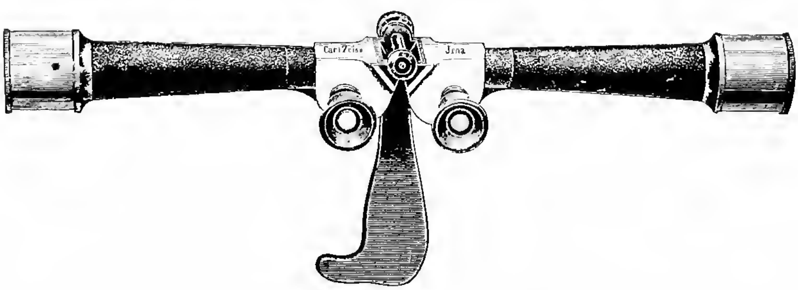


Fig. 52. Stereo-telescope fully extended.

depends on the use of two eyes, in consequence of which an object can be seen from different points of view, it will be readily understood that an instrument in which the inter-ocular distance is virtually increased, must, by virtue of this increase, confer increased stereoscopic power upon the user of the field-glass.

This fact has been to a moderate extent utilised at Jena in the construction of the "Zeiss Field-glass" (Figs. 49 and 50), which is adapted for use by tourists, sportsmen, sailors, etc., and in which, the inter-objective distance being almost double the inter-ocular distance, the stereoscopic power is consequently increased in the same proportion. In the stereo-telescopes (Figs. 51 to 53) the inter-objective distance is from five to ten times the inter-ocular distance, with a corresponding increase in the stereoscopic power. These instruments are sometimes called "scissors telescopes," because the two arms can be rotated and the instrument used either with the arms folded together or extended. If used in the first way, the observer may remain under cover; if in the second, a greater stereoscopic power is obtained. The field-glasses are made with linear magnifying powers of from three to twelve. It is only necessary to compare them with a glass of the older construction to see how much handier they are, and how much larger is their field of view. It is also worth remembering that in the case of any of the Jena glasses the real magnifying power is always stated—a kind of frankness without precedent in this branch of optics. All these instruments are, moreover, so constructed that each of the two oculars can be independently adjusted to suit the corresponding eye of the observer; it being well known that inequalities of sight occur between the two eyes of many persons. The distance between the two oculars can also be adjusted to the distance between the eyes of the observer. All these adjustments are effected with the aid of graduated scales, so that the owner having once determined them and noted the readings can, at any time, reset them. With each instrument there is supplied a very ingenious, but simple and sufficiently-accurate appliance, for measuring the inter-pupil distance, having a range of from 50mm. to 80mm.

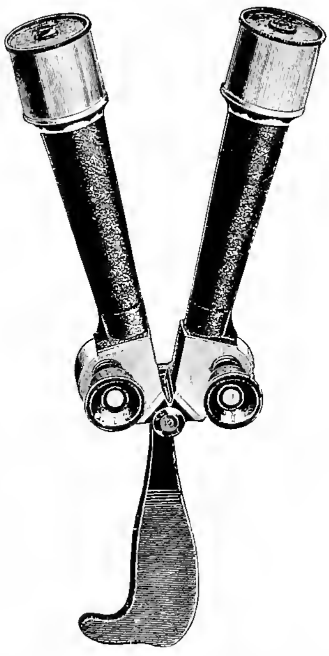


Fig. 53. Stereo-telescope folded up.

A more delicate modification is supplied to oculists. How great a want has been met by this field-glass, and how popular it has become in a very short time, is shown by the fact that 10,000 of them are manufactured and sold annually, not including imitations and instruments manufactured under license. When the magnifying power is greater than twelve, the instrument

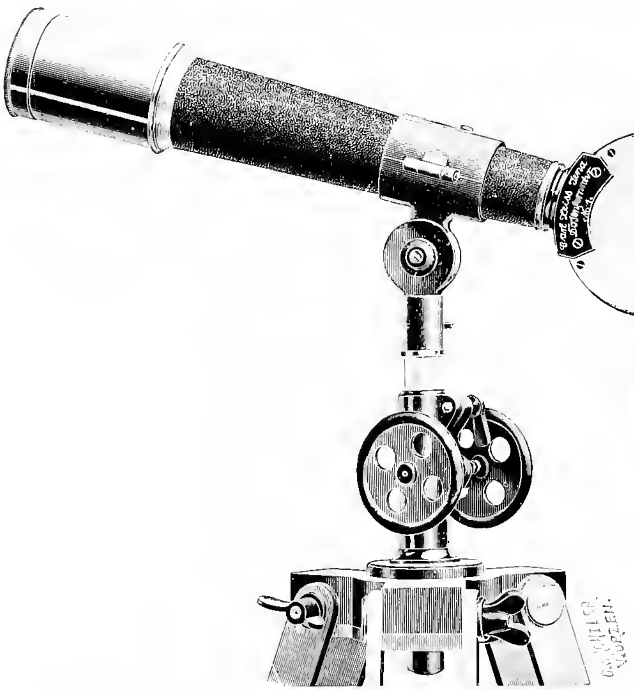


Fig. 54. Telescope with an Interchangeable "Capstan" Eyepiece, mounted on stand.

becomes clumsy: the stand telescopes, monocular and binocular, are then the better instruments.

The terrestrial-telescope department is under the direction of Dr. Albert König, who is assisted in his labours by Lieut. Braun and Dr. v. Hofe.

We will close this chapter with an observation on the curious way in which new discoveries are frequently developed. Neither of the two ideas on which the value of the Zeiss field-glasses depends—the erecting of the image by a set of prisms, and the increased inter-objective distance—was originated at Jena. The prism combination was first invented, a good many years ago, by the Italian engineer, Porro, although the fact was only discovered when the

Zeiss construction was examined by the German Patent Office. The principle on which the increased stereoscopic power depends was discovered by no less a person than Helmholtz, who based his "tele-stereoscope" on it. But neither Porro's nor Helmholtz' invention was successful in practice, because neither by itself was of sufficient practical importance. Only by combining both ideas, by furnishing the tele-stereoscope of Helmholtz with the prisms of

Fig. 55. Adjusting a Binocular Stand-Telescope.

Porro, did success become possible. The merit of effecting this combination, successfully and practically, undoubtedly belongs to the Jena Works.

A special paragraph must be devoted to the consideration of the Zeiss range--finder, the conception of which was due to De Grousillier (Fig. 56). This instrument is noteworthy on account of the importance of the problem it is destined to solve, the manner in which it solves it, and the interesting principle upon which the solution is based. For ages many persons, fitted and unfitted for the task, have attacked the problem of determining the range or distance of an object in the landscape from a fixed

observer. There are few words which occur more often in the yearly patent lists than the word "range-finder." The Zeiss range-finder differs from all others in that it is based upon binocular, or stereoscopic vision, the power of which is enhanced by an increased inter-objective distance. This increase of the inter-objective distance is necessary for the discrimination, with any approach

Fig. 56. Range-finder on stand.

to accuracy, of differences in the distances of objects. To understand the principle upon which the instrument depends for its value, let us imagine a stereo-telescope, i.e., a binocular telescope with a magnified inter-objective distance, with its eye-pieces fitted with two scales, which may be looked upon as a pair of stereoscopic photographs of a long line of measuring posts, ranging

over an indefinitely extended plain. Looking through such an instrument, the scales will be seen stereoscopically combined, and thus virtually projected into space (Fig. 57). In other words the scale, although situated in a plane in the eye-pieces, is seen as though a stereoscopic feature of the landscape. If then, for example, it is desired to ascertain the distance of a church steeple, all that is required is to note the numbered scale divisions between which it is apparently and stereoscopically seen in the field of view of the instrument. The distance, to the fraction of a division, may be thus read off directly. It is scarcely possible to imagine

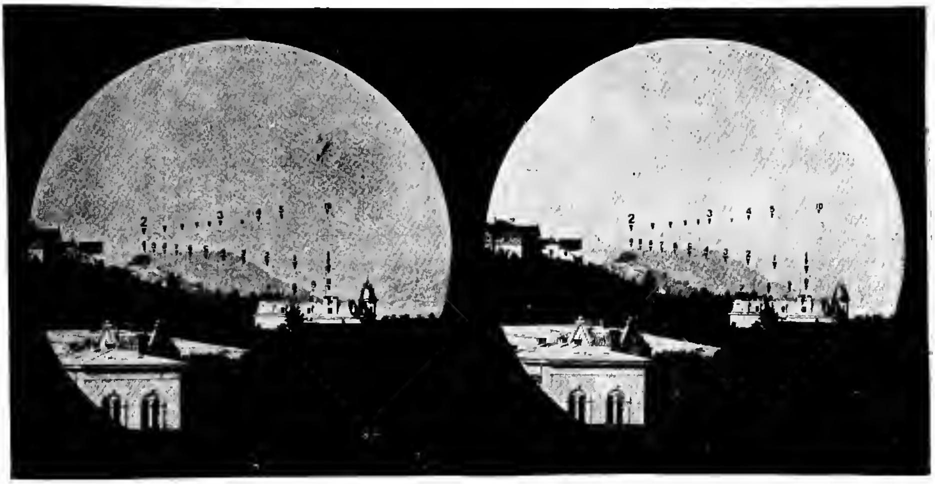


Fig 57. Stereograph with Distance Scale to illustrate the principle of the Range-finder.

the almost absurd ease and simplicity with which the instrument can be used. The landscape seems to be provided with a long line of numbered distance posts, in whichever direction the instrument is directed, against which distances are read off. The accuracy of the measurements depends on the inter-objective distance and the magnifying power of the instrument. In the small model, with an inter-objective distance or base of 0·5 meters, and a magnifying power of 8, the error at a distance of 500 meters may amount to 10 meters, and at a distance of 1,000 meters to less than 40 meters. When the large model is used with a base of 1·5 meters, and a magnifying power of 23, the error at 1,000 meters only amounts to from 4 to 5 meters, and at 3,000 meters to about 40 meters. The error, it will be seen, increases at a greater rate than the distance.

There can be no question as to the superiority of the binocular range-finder over all other similar instruments. It might almost be considered an ideal instrument, if that did not presuppose the possession by the observer of a pair of sound eyes of approximately equal visual power, an assumption, however, fortunately correct in the case of the great majority of men.

The Measuring-Instrument Department.

ALL the instruments we have hitherto considered have been instruments for aiding the vision, some directly, and others indirectly, as by the production of photographic images. We now come to consider a different class of instrument—those

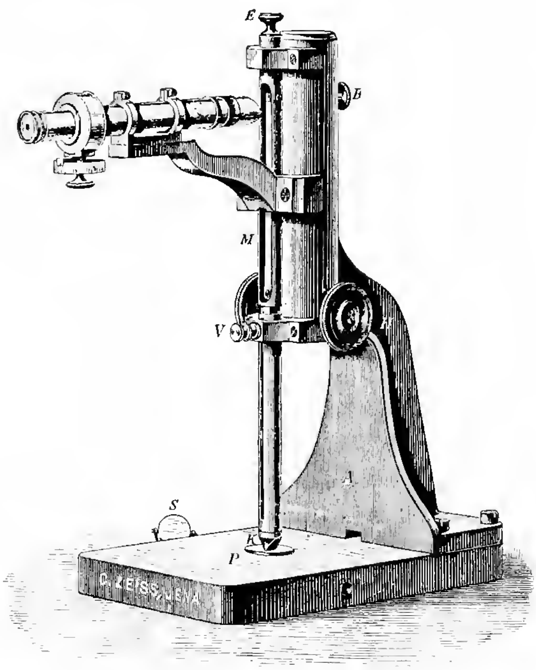


Fig. 58. Abbe's Thickness Gauge.

designed for measuring purposes. Some of these are for strictly scientific purposes, whilst others are of great commercial importance. The number of instruments of this class manufactured at

the Jena Works is so great that we must limit ourselves to mentioning only a few of the more interesting ones.

The department, which since its foundation has been admirably managed by Dr. Carl Pulfrich, with Dr. Löwe as assistant, originated in a natural desire to design and construct the instruments necessary for making the various measurements required daily in the workshops, as, for instance, the thicknesses

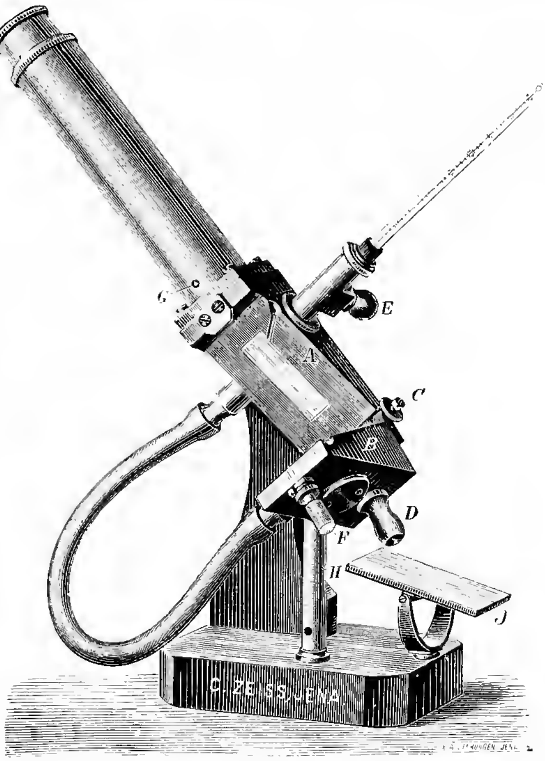


Fig. 59. Butter Refractometer.

of glass plates, the angles of prisms, the refractive indices of different kinds of glass and crystals, the curvatures and focal lengths of lenses, and the like. The difficulty of the task will be apparent when it is remembered that the magnitudes to be measured frequently amount to not more than the one-thousandth part of a millimeter or a degree, or even less, in magnitudes to be determined to five or six significant figures. After many years of labour and much money had been spent in perfecting instruments suitable for these purposes, it was natural

that the experience gained should be turned to useful account in the manufacture and sale of these instruments to others, who thus became possessed of instruments of greater accuracy and usefulness than any which had heretofore been constructed.

Examples of instruments of the class referred to are Abbe's thickness-gauge, Fig. 58; the spherometer for determining radii of curvature; the focometer for measuring focal lengths; Abbe's dilato-

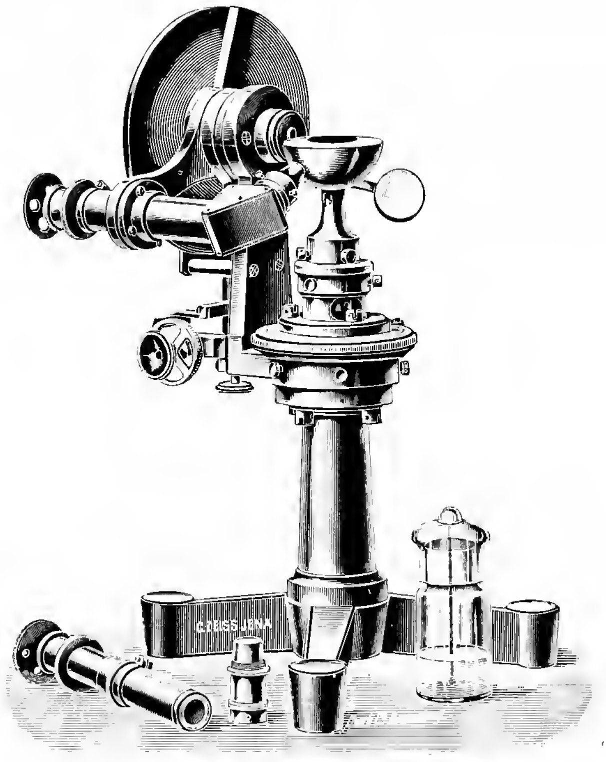


Fig. 60. Abbe's Refractometer.

meter for measuring infinitesimally small changes of length and thickness, due, for instance, to variation of temperature; and the various spectrometers and refractometers for the quantitative investigation of the refractive and dispersive powers of solid bodies, especially of crystals and liquids; these instruments being either of very complicated construction for the most delicate scientific investigations, or, designed for quick and handy use in every-day operations, such as milk and butter testing, etc.

During the last few years the measuring-instrument department,

influenced by the speculations and the systematically conducted investigations of its head, has taken in hand a new subject—stereo-

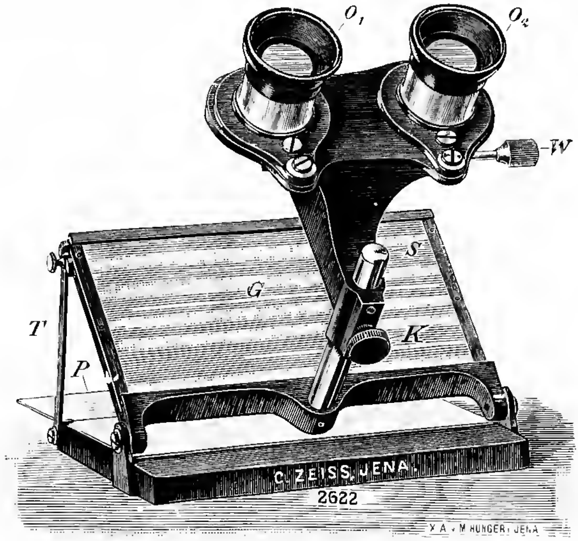


Fig. 61. Stereoscope.

scopic observation and measurement. Everyone knows the stereoscope, an instrument for enabling two images of one object, taken

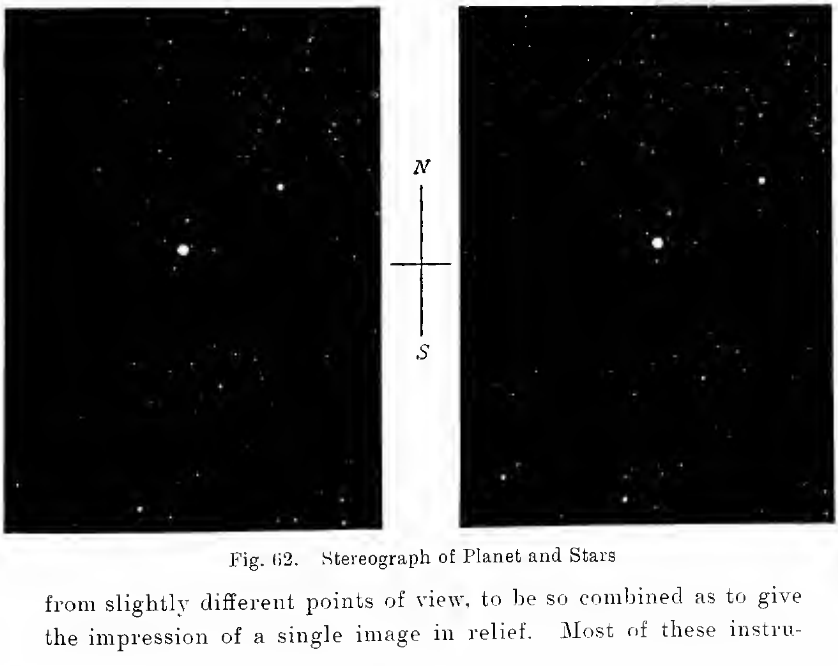


Fig. 62. Stereograph of Planet and Stars

from slightly different points of view, to be so combined as to give the impression of a single image in relief. Most of these instru-

ments are by no means perfect, although it need scarcely be said that those made by Zeiss are much superior to the ordinary ones. Special attention is called to the small stereoscope, illustrated by Fig. 61, with which some particularly interesting stereoscopic slides, or stereographs, are supplied. Another form of stereoscope, which satisfies still more exacting requirements, is supplied for special purposes in which great stereoscopic depth of vision is required.

Fig. 63. Stereo-comparator.

But the "marvel" of the department is the stereo-comparator, Fig. 63. This is, in fact, a stereoscope in which, in consequence of the immense extension of the equivalent inter-objective distance, that is, the distance between the two points from which the two photographs are taken, the stereoscopic power is so enormous that exact measurements of the distances of the objects pictured become possible. To do this, all that is necessary, whilst looking into the instrument, is to adjust a pointer, which can be moved from right to left, and up and down, until it seems to reach and touch the object the distance of which is required. It is obvious that by means of this instrument it becomes possible to make many measurements which

cannot be determined in the ordinary manner—it may be because the objects are inaccessible, because they change too quickly, because it is not possible to give the necessary time, or because the time during which it is possible to make exact measurements is too short. The instrument may be employed to determine the physical form, or shape, of various bodies, organisms and organs, by taking instantaneous and time photographs of them. In this way very fine distinctions existing between objects supposed to be alike, or very similar, may be ascertained; or it may be determined whether one and the same object has changed during the period which has elapsed between the taking of two photographs. But most important is the use which may be made of the stereo-comparator for astronomical and topographical purposes. In making astronomical observations photography has been employed, as is well known, for a considerable time past; in future stereo-photography will be available. The base-line for the two photographs required is, of course, obtained by allowing a certain time to elapse between taking the two pictures. In this way it is possible, for instance, to obtain photographs giving so much relief, that the mountains and valleys of the moon may be measured and plumbed with an astonishing degree of accuracy. If a group of stars be photographed when a planet happens to be amongst them, it will be identified by being seen standing out in space in front of the fixed stars, as in Fig. 62. The positions of the moons of Jupiter in relation to the planet, is another good subject for a stereo-photographic picture.

The advantages of the instrument for making topographical observations need scarcely be dwelt upon. The observer is independent of wind and weather; instead of spending days in a district, hours will now suffice. At the same time a high degree of accuracy can be guaranteed, as has been proved by means of experimental photographs of a carefully surveyed district. Moreover, by the invention of the stereo-planigraph, which differs in one important respect from the stereo-comparator, Dr. Pulfrich has placed a second valuable instrument at the disposal of all whose business or interest it is to make topographical measurements. By means of these two instruments it is now possible to so divide the work that the trigonometrical data are obtained by the help of the first and the topographical details by the help of the second instrument.

The separate departments have now been successively reviewed. One matter of interest, however, still remains. An enterprise which is constantly engaged in grappling with new scientific problems, the solution of which might have technical value, must deal from time to time with questions which do not readily admit of being referred to any particular department, but the solution of which might benefit one department or the other, and might even lead to the formation of new departments. The necessary work in connection with these problems is undertaken principally by the scientific leaders of the enterprise, assisted, amongst others, by Drs. Riedel, Siedentopf, Herschkowitsch, Henker and Ehlers.

The Enlargement of the Premises.

IT is one of the disadvantages of the method adopted by us for acquainting the reader with the scope of the work carried on at the Jena Works, that the impression given must be of a somewhat disjointed character. To rectify this we can do nothing better than visit the place itself in imagination and see with our own eyes how the raw materials are worked up into the different articles of which we have spoken. But before we start on our visit we must give a slight historical sketch of the origin and growth of the business premises.

When Carl Zeiss opened his shop in 1846, he first established himself in the Neugasse, but soon removed to the Wagnergasse (see Figs. 1 and 2). At both places the business was carried on in small hired rooms, adapted, as well as might be, for the purpose. At the beginning he only employed one journeyman and two apprentices, and for some time his staff did not materially increase.

Nothing can be more interesting to anyone acquainted with the present gigantic proportions of the business than to listen to some of the stories of old Löber, the sole survivor of that period. "As," says Löber, "there was very often no optical work to be done, I had to take a share of the mechanical. During the year 1848, the year of the Revolution, Mr. Zeiss joined the Militia. At the shop, where regular business had practically come to a standstill, we occupied ourselves by converting old flint-locks into percussion-locks, filing and hardening gun-cocks. . . . During the fifties,

trade was so much upset by commercial crises and high prices that the single journeyman had to be dismissed, leaving Mr. Zeiss and myself to form the whole staff. From all this it will easily be guessed that the flesh-pots of Egypt were often but sparingly filled. I remember that Mr. Zeiss' breakfast occasionally consisted of about a ha'puth of bread and a small glass of schnaps, of which I've sometimes had a taste, when I happened to come across him at his meals. . . . Sometimes I was fetched away from my Sunday work—gardening—to sell a beggarly pair of spectacles for 1s. 9d.—I need scarcely say that I was not in any danger of getting too fat. . . ."

In 1857 the business was removed to premises at the Johannisplatz (Fig. 64), the available space of which seemed not only sufficient to provide for the needs of the time, but for any possible extension even in the more distant future. It was an agreeable surprise to find that this expectation was not realised. During the time the business was carried on at the Johannisplatz, three remarkable events were celebrated: the completion of the thousandth microscope on May 28th, 1866, the two-thousandth on September 12th, 1873, and the three-thousandth towards the end of September, 1876. By this time the premises had become too small. The realisation of the homogeneous-immersion principle, and the growing demand for the productions of the concern, made it necessary to increase the number of workmen employed, first to 50, and then to greater numbers. It was thought wise, therefore, to buy the extensive plot of land between the Krautgasse and the Leutrabach, at that time practically outside the town, and to start immediately erecting well-lighted and well-ventilated workshops. If it had only been possible to foresee the quick growth of the town and the development of the business—of course there was a close connection between the two—the site chosen would have been undoubtedly still further away. It is undeniably an advantage to

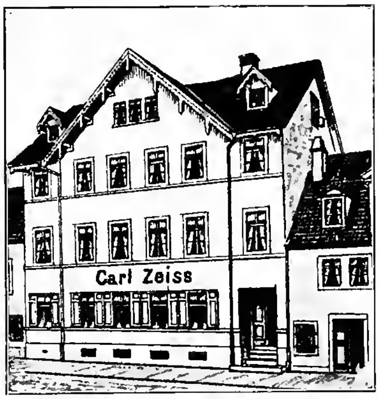


Fig. 64. Third Workshop in the Johannisplatz.

have the Works, which now comprise nearly a quarter of the town (see the frontispiece, Fig. 65), situated near the centre of it; yet against this must be set the fact that the surrounding ground, which has been covered in the meantime with private buildings, has acquired such a high value, that it now appears scarcely possible to extend the present premises in any direction whatever. During the years the writer has been able, personally, to follow the course of development, that is, since 1890, scarcely a year has passed without the addition of new, or the extension of old premises. At the present time the Works embrace an area of more than three acres, of which not quite half is built on; whilst the total area covered by the different floors of the various buildings amounts to nearly four acres. If we consider that at other works such a space is considered to be large enough for between 3,000 and 6,000 workers, whilst at Jena it is considered to be just large enough for between 1,300 and 1,400 only, it will become clear how much working space each individual enjoys, and how pleasant even the external surroundings have been made for all employed. The same liberality has also been observed in regard to the height of the rooms, and the heating and ventilating systems, which have been carried out under the direction of the Sanitary Authorities of the University, and in many other respects.

A Stroll round the Works.

IF we decide to begin by visiting the plant which produces the power for the whole of the undertaking, we are met at once with evidence that the growth of the business premises at the Carl-Zeiss Platz has not kept pace with the enormous expansion of the business itself. To reach the south end of the town, where the electric-power station, built in 1902 to provide for the requirements of the Optical Works and the Glass Works, is situated, necessitates about a quarter-of-an-hour's walk. As the town of Jena had only recently erected an electric-power station, the question arose whether it wonld not be better to enter into business relations with it. This question was decided in the negative, not only because the plant which supplies direct current happened to be situated at the other end of the town, but princi-

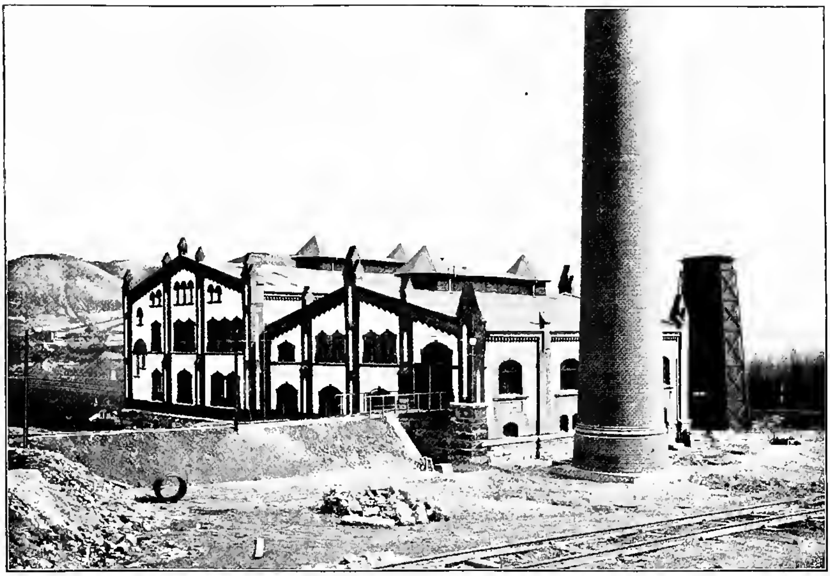


Fig. 66. Electric-power Station.

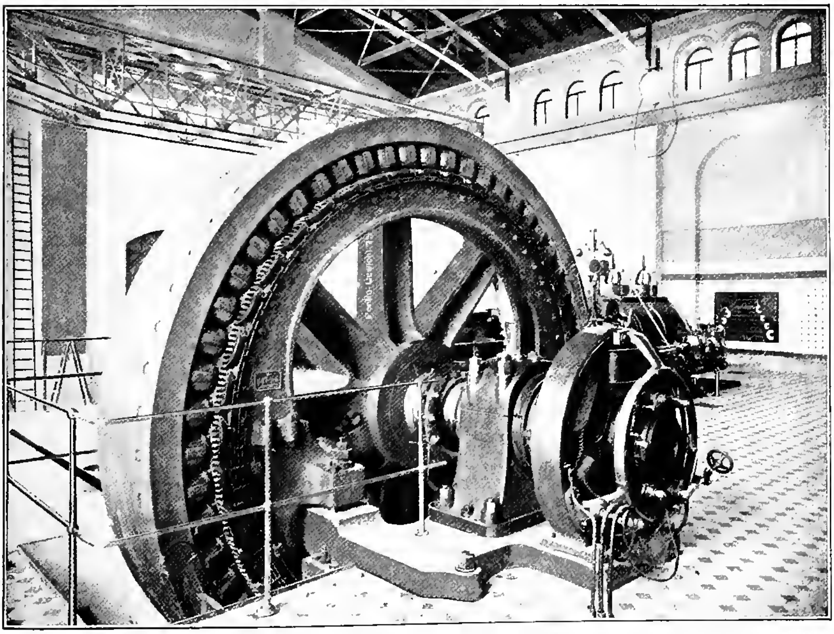


Fig. 67. 450-H.P. direct-driven Dynamo of the new Electric-power Station.

pally because it was not thought wise for so large an enterprise, as the combined Optical and Glass Works, to be dependent on an undertaking in the management of which it could not have a determining voice. The circumstance that one half of the whole power generated would have been taken by a single customer, would not have been conducive to the advantage of both parties.

The power produced in the electric-power station, so far as it is not required by the Glass Works, is conducted by high-pressure currents to the Zeiss Works, where it is distributed in the usual way to the different workshops, and used either for driving the

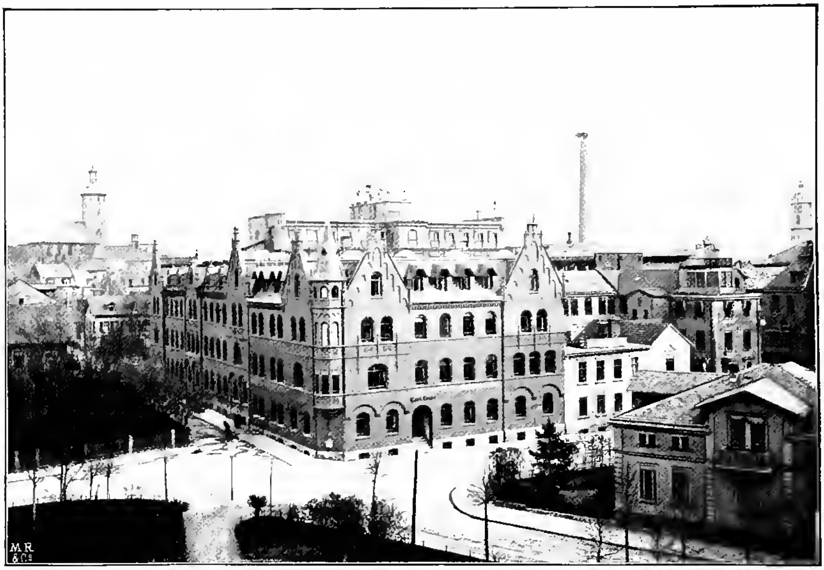


Fig. 68. Offices of the Administration.

machinery or for illuminating purposes. The small 130 h.p. plant, by means of which the Works used to be supplied, has not been removed, but is maintained in readiness for emergencies.

We enter the Carl-Zeiss Works through the large and handsome corner building, which contains the various administrative offices and laboratories, but we cannot tarry here. In passing, however, we may glance into the room where the productions of the Works are submitted to a final examination before being sent out. Our course through the Works will now depend on whether we are more interested in the optical or the mechanical departments, but it will perhaps be better to take the latter first and leave the optical departments to the last.

We then first visit the building set apart for the moulding and casting of metals—the foundry—which is supplied with its raw materials from the storehouse ; in which also the partly-worked details are sorted and kept. The various castings, when made, are sent to this building. The metals used for the different alloys are principally copper, tin, zinc, and, during the last ten years, aluminium. The metallurgical laboratory, started a few years ago under the scientific direction of Dr. Herschkowitsch, has been so successful in

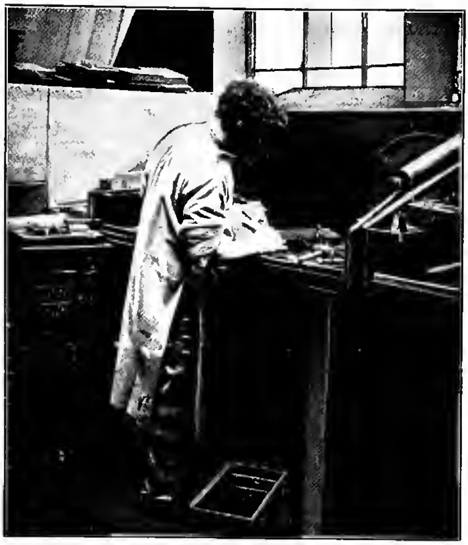


Fig. 69. Foundry.

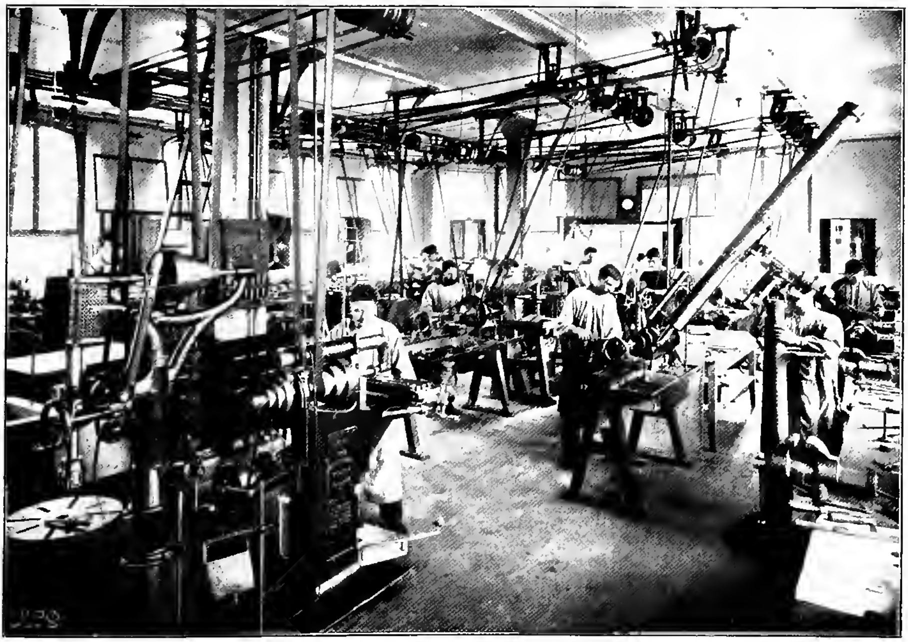


Fig. 70. Astronomical Workshop.

the manufacture of old and new alloys that the products of the foundry are now equal to any made in Germany. In response to numerous requests, the execution of outside orders for castings has of late been undertaken. From the storehouse the castings are distributed to the shaping, turning, milling and other metal-working shops, and when finished they are returned to it, to be finally sent to the various departments referred to earlier in this book. All the various operations to which the metal parts are subjected are carried out strictly in accordance with specifications and drawings, and each part, before being sent on to

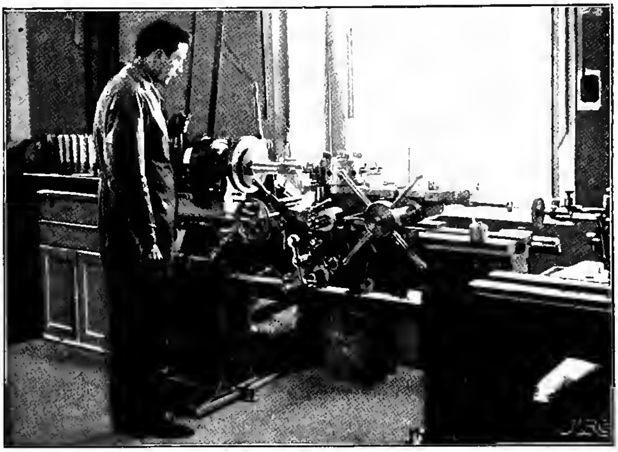


Fig. 71. Capstan Lathe.

the next shop to be dealt with, is carefully tested by the foreman of the department, and if not up to the standard, is either sent back to be perfected, or, if that cannot be done, destroyed. New constructions, and special orders for apparatus for the purposes of research and demonstration, of which a large number are received annually from *savants*, are, of course, treated specially. Although these special orders, in many cases, do not even pay the cost of execution, they are, notwithstanding, invariably accepted for the sake of any new ideas which they may suggest, if they come legitimately within the province of the undertaking. These new constructions, after all the questions involved have been carefully considered by the scientific staff, and the necessary data determined, are passed on to the constructing department, where the drawings are prepared and finally approved before the actual manufacture begins.

Adjoining the storehouse are the turning shops already mentioned, in which capstan lathes are principally employed. Adjoining them are the milling and shaping shops, in which are found a number of highly ingenious machines for special purposes, most of which have been designed and constructed in the tool shops of the Works.

Following the order of manufacture we now enter the erecting

Fig. 72. Surfacing the Horseshoe-feet of Microscopes.

shops, where the different parts of the varions instruments are finally fitted and assembled; to be again taken apart and sent, each piece ticketed with its serial number, to the polishing and lacquering shops to be cleansed, partially coloured by means of different acid mixtures, or blackened and finally polished and lacquered. There are also carpentering and leather-working shops for the manufacture of the cases of the instruments, packing cases for their transport, and the like.

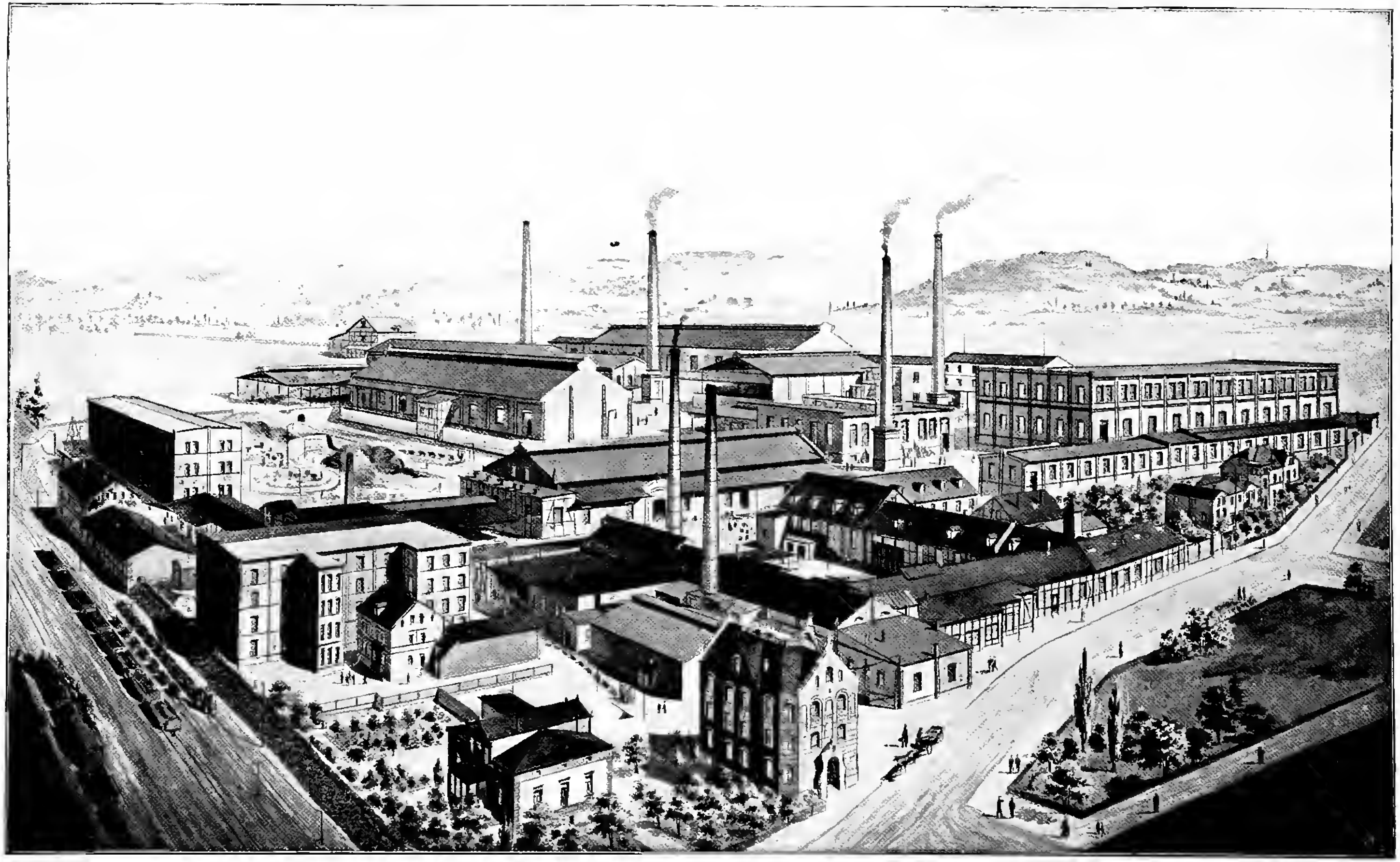


Fig. 73. The Glass Works of Schott & Genossen.

We now come to the strictly optical department, which is concerned, not with metal, but with glasses of the most diverse characters. Besides glass, some natural crystals such as fluor spar, quartz and Iceland spar are used, but only for special purposes.

If time permitted, it would be interesting to turn aside to pay a visit to the Glass Works of Schott & Genossen, Fig. 73, where

Fig. 74. Casting a large Telescope Lens.

the glass used at the Optical Works is manufactured. If we did so we should see the raw materials, collected from different parts of the world, and the furnaces, from which the hot molten mass is taken. The glass is mostly cast in the form of slabs, which are ground and polished on opposite sides to allow of testing for freedom from striæ and other defects. Only the largest astronomical object-glasses are cast to shape in open moulds. One side of each of the rough lenses cast in this manner is conse-

quently convex, whilst the other is flat. The pouring out of such an immense mass of white-hot matter offers a magnificent spectacle, and is an operation which must be carried out in the most careful and exact manner, if the result is to be satisfactory, Fig. 74.

We must now retrace our steps to the Optical Works in the Carl-Zeiss Platz, where the slabs just mentioned are sawn into

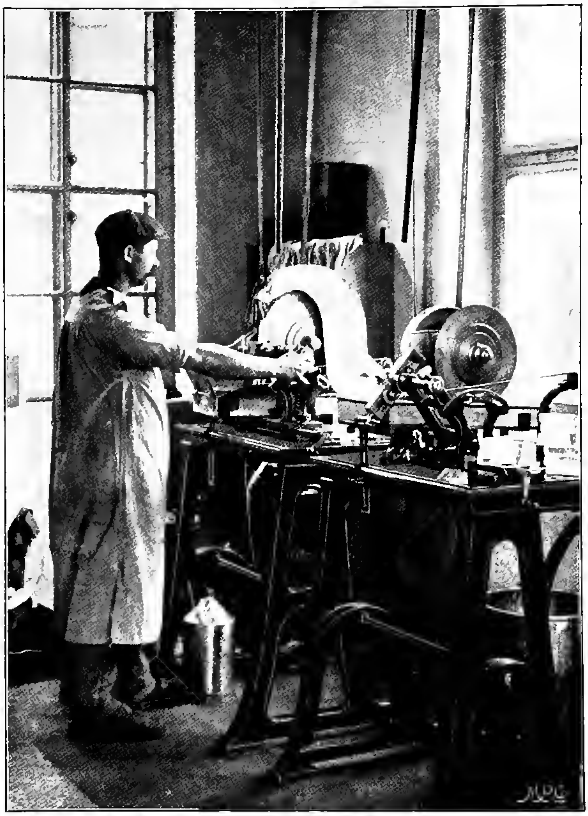


Fig. 75. Glass slitting.

prisms, or into smaller pieces for lenses, by means of circular discs of sheet-iron, or tin-plate, the edges of which are armed with diamond dust, and lubricated with petroleum. We next pass to the rooms where the prisms and lenses are ground. This operation requires a great deal of space, because of the necessity for different and separate machines for each size and kind of prism or lens. All the prisms and lenses, with the exception of the giant object-glasses already referred to, pass through these

rooms. After the pieces of glass have had their surfaces subjected to the various grinding operations, they are sent to the polishing room, where they undergo the last and most difficult operation. In this room lenses of great curvature are polished singly, whilst those of small curvature are treated in batches of as many as fifty. For this purpose they are cemented to a common support, in such a manner that the curvature of the spherical surface formed by the whole number of lenses is the same as that of each single lens, when its polishing is completed. These lenses are pressed into an electrically-rotated grinding cup, and are given during the operation a rolling and pitching motion, similar to that of a point on a ship. Of course, it is obvious that only a

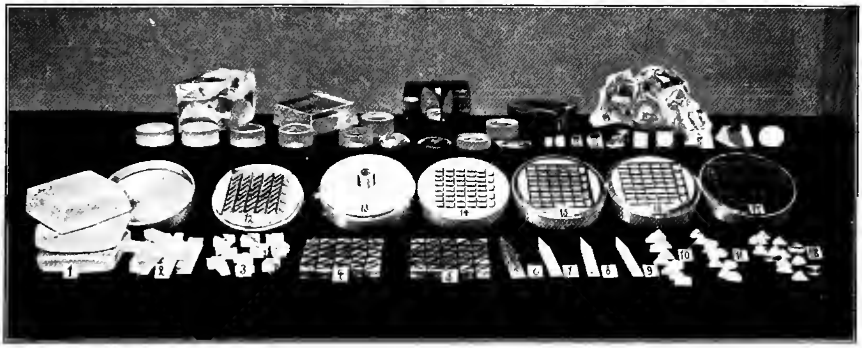


Fig. 76. Stages in the Manufacture of Prisms.

workman of great practical experience, a man who knows exactly when to increase and when to decrease the pressure, will be able to produce lenses, the curvatures of which are uniform and accurate. From time to time he must interrupt the work, and by means of the Fraunhofer-Löber method, test its progress. In this method a mathematically-accurate test-plate, with a curvature exactly equal and opposite to that required, gives the well-known Newton's rings, in which the variation in the thickness of the layer of air between the worked surface and the test-plate, from one ring to the next of the same colour, amounts to less than 0.0003mm.

Very small lenses for microscope objectives, which require the most delicate manipulation, do not pass through so many different hands. The front lenses of oil-immersion objectives, for instance, which are hemispherical, or even hyper-hemispherical, are made by hand, and not by machinery, from a small glass plate polished on one side only.

Fig. 77. Polishing Lenses.

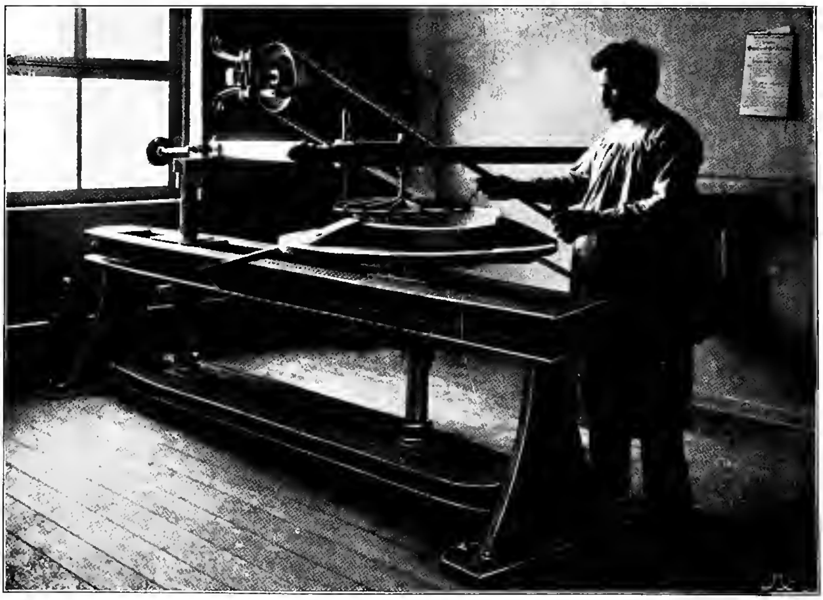


Fig. 78. Machine for polishing large Lenses.

When the surfaces of the lenses have been ground and polished, the lenses are taken to a room where they are fastened to the end of a lathe spindle with pitch, and having been centred by means of a testing lever, are then reduced to the required diameter by grinding with emery on a strip of curved sheet-iron. The testing room for lenses adjoins that in which this operation is carried on. In it are stored about 20,000 testing plates or cups, with 700 different radii of curvature; as well as about 70 different types of glass, each represented by a number of varieties. This storehouse for the glass parts may be said to be the counterpart of that for the metal parts of the various instruments, referred to in the beginning of this chapter.

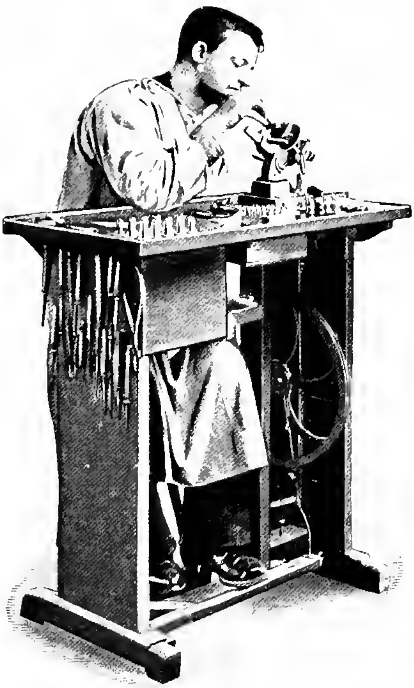


Fig. 79. Mounting Microscope-objective Lenses.

In addition to the various buildings spoken of, the Works contain a studio for photographic experiments, and another for photographic reproduction; two studios for photomicrography and projection; a library, which promises to become in course of time an archive of practical optics; and many other buildings, which cannot be separately mentioned.

In conclusion we must mention, for the sake of completeness, the branch establishments at Berlin, Vienna, Frankfort, Hamburg, London and St. Petersburg, where the products of the Works can be obtained, and where also small repairs can be effected by workmen who have been trained at Jena.

The Ownership of the Works.

IT is usual, when describing an industrial undertaking, to add, as a kind of appendix, some remarks respecting the social condition of the employees, and the benefits conferred on them by the firm. When speaking of the Optical Works at Jena, it is, however, necessary to deal with the matter in a very different spirit, and to point out that the importance of this branch of the subject is quite equal to that dealt with in the earlier chapters. Whilst the Zeiss Works is certainly justified in claiming that the instruments turned out in its different workshops are models for the whole world, it is, at least, equally justified in making this claim for the social organisation it has built up. If the space at our disposal had been allotted in accordance with the interest the general reader might be expected to feel in our subject, a much larger share of that space would undoubtedly have had to be given to that section with which we are now going to deal. After all, Optics is but Optics, and the world could, if necessary, get on without it. But whether there will ever come a time when the industrial world will be able to exist without some kind of definite social organisation, adapted to and changing with changing conditions, is still an unanswered question. And the social organisation devised at Jena is a model of what such an organisation should be.

For nearly thirty years, from 1846 to 1875, Carl Zeiss was sole proprietor of the business founded by him. He retained this position even after the united efforts of himself and Abbe had begun to bear fruit. But when, in consequence of increasing success, it became necessary to extend the range of operations, and to invest larger funds in the undertaking, it became clear to Zeiss that his colleague should be permanently attached to the business. It would be taking a one-sided view to say that Zeiss took Abbe into partnership solely in grateful recognition of his services. Whilst, no doubt, this motive influenced his action to a certain extent, it is equally true that he desired that Abbe should share some of the risks of the future.

From 1875 Carl Zeiss and Ernst Abbe were the proprietors, to be joined, in 1881, by Zeiss' eldest son, Dr. Roderich Zeiss. Without offending the susceptibilities of anyone, it may be stated that Abbe and Roderich Zeiss were not men who could be expected to

work harmoniously together; their conceptions of life, their ways of looking at things, were utterly different. What actually came to pass was really unavoidable; any other result would almost have amounted to a contradiction of what has been said in an earlier chapter about the rare chance which united two men so well fitted to work together as the elder Zeiss and Abbe. Scarcely a year after the death of Carl Zeiss, in 1888, Roderich retired from the management and thereby actually, although not formally, severed his connection with the business. Abbe was now sole proprietor, and it will be interesting to know to what use he put his power. The fruits of that short period of autocratic power are not great in number. They consisted of a single act only, but this act was of such surprising grandeur, that nobody could have expected it to ripen under the leaden sky of modern industrial life. It was an act not only great in itself, but rich and fruitful to generations yet unborn, which will reap benefits derived from it. Abbe's achievement was the creation of the Carl-Zeiss Stiftung, which he named after his late colleague, and to which, in 1891, he ceded all his proprietary rights, both in the Optical Works and the Glass Works.

The Carl-Zeiss Stiftung.

WERE human life interminable, or human experience cumulative, in the sense that an unbroken continuity of intellectual and moral activity could be maintained amongst the individual units who successively replace each other, the realisation of the highest social ideal would undoubtedly be attained by placing every kind of enterprise under the control of a single individual, who, being a free agent, and in possession of beliefs and convictions based on a true ethical and intellectual conception of the fitness of things, would be both able and willing to accomodate his actions to the requirements of the changing circumstances of his time. No written constitution, however well devised, could, in comparison with such an administrator, be otherwise than imperfect and arbitrary. Such a conception of human activity is, unfortunately, but a figment of the imagination. Not only does man die, but with him die all his plans, and all his power of carrying them into

execution ; even a son differs from his father, and how much more then one stranger following another. So much depends upon the personal equation. However little even the best written constitution may be able to replace an ideal personality, it is yet in the highest degree preferable to the indeterminable caprices due to individual temperament and ability.

That some such line of thought, as the foregoing, seems to have led up to Abbe's decision may be inferred from the introductory words of the circular in which he notified to his fellow-workers the completion of the transfer to the Stiftung of the property of the firm of Carl Zeiss, including its share in the Glass Works :—" To enable me the better to ensure that the present economic condition, and satisfactory administration of both undertakings shall, even in the distant future, be maintained more effectually than can in the long-run be expected under private proprietorship, and to this end to make preparations during my lifetime, I have, etc." Even those who read the Statutes without actual knowledge that they are the outcome of years of thought, mental struggle and careful consideration, will during their reading become aware that the author of them must have perceived on many occasions, even while framing a regulation, that it was either capable of improvement, or, at best, nothing more than the choice of the least evil. It will be obvious that he must often have hesitated as to the best way of framing one or another provision, and that his final decision was always dictated by the necessity for the subordination of the various parts to the whole. Although Abbe may have listened to the advice and suggestions of intimate friends, the Statutes, for which the faculty of Law of the University of Jena conferred upon him the honorary Doctor's degree, were none the less his own work. The greatness of Abbe's achievement, which consists in his having so completely solved so novel a problem, is not lessened by the fact that it is subject to those imperfections which are inherent in every law and regulation which restricts the freedom of individual and instantaneous decision. Circumstances may be imagined under which the people responsible for the management of the Works, might consider one or another rule prejudicial to the interests of the Stiftung, or might even feel more strongly with regard to it ; but, in accordance with the spirit of the founder, the reasons which dictated the rule in question, and which render it indispensable to the well-being of the entire undertaking, will always be borne in mind. In view of the fact that improvement can only be attained as the result of experience, it need scarcely be stated

that a mode of procedure has been laid down for effecting alterations in the Statutes. This can be done in the following manner:—For the first ten years of the existence of the Statutes —that is to say until 1906—they can be modified and amended, authoritative explanations thereof can be issued, and, if necessary, entire articles can be recast, upon the agreement of the Administration of the Stiftung and the founder. These regulations acquire legal validity as soon as they have been confirmed by the State. After the lapse of the first ten years a totally different mode of procedure will have to be adopted. Changes then will only be permitted in cases where the legal basis, or the technical and economic conditions on which the efficiency of the Stiftung depends, have changed to such an extent that compliance with the regulations laid down in the Statutes would either be impossible; impracticable, in consequence of the results to which it would lead; or manifestly opposed to the intention of the founder. Proposed alterations, of the character above indicated, must be submitted to the trustee, the boards of management, partners, the employees, the descendants of the founder, the university, and the municipal authorities; and they acquire legal validity only after the lapse of a year, and after any objections raised have been settled by the proper legal authorities. Under no circumstances is it permissible to alter this mode of procedure, or anything in the first four articles of the Statutes, relating to the name, object, and location of the Stiftung, and the constitution of its administrative bodies; neither is it permissible to exclude individuals or groups of individuals from the effect of a change of the Statutes, nor to compensate them therefor.

The Statutes of the Carl-Zeiss Stiftung, which had already been provisionally reduced to practice, were confirmed by the Grand Duke of Saxony on the first day of October, 1896, and have had, since then, the full force of law. Guided by their provisions, we will now consider the most important of the special aspects of the undertaking, and will also deal with those points which are not explicitly referred to in the Statutes. But before doing so some general considerations do not seem out of place.

Individuals who have given largely for charitable and benevolent objects are usually characterised as generous; and in conformity with this view the action of Abbe in founding the Carl-Zeiss Stiftung has generally been praised as an example of great generosity. Considering the action *per se*, such praise is undoubtedly merited; it would be difficult, at all events in Germany,

to find many instances of like generosity. But bearing in mind the motive by which the action was prompted, it seems to us that the word "generous" scarcely does full justice to Abbe. His act was not merely an act of benevolence differing from other like acts only in respect of the magnitude of the sum involved. In acting as he did, he only carried out, in accordance with his lofty ethical principles, what he conceived to be a sacred duty toward the enterprise with which he was connected, its employees, and the commonwealth. His act was none the less meritorious because he conceived it to be an act of duty; on the contrary, the fact that he felt it to be a duty, places him on a much higher plane than that occupied by those whose sole merit consists in their having performed a worthy act.

Who is the rightful owner of a factory? To this question a great many answers might be given; we need, however, only concern ourselves with those two that correspond to the two extreme points of view. Some consider the moral right to be incontestably on the side of the capitalist, whilst others make the same claim on behalf of the worker. The first alternative is the one which is almost universally recognised in practice; the second has been recognised and put into practice only in a few exceptional instances, and these have not invariably been attended with satisfactory results. Both positions are equally one-sided. It must be allowed that in strict justice, all those have a right to be considered proprietors who have been concerned in the foundation of an enterprise, or who are, or will be, concerned in its maintenance and expansion. Of these three parties, the claims of the living are most easily satisfied, as, for instance, by the payment of salaries or wages, profit-sharing, insurance against illness and old age, and like measures, all of which will be considered in detail later on. But how shall justice be done to the dead, and to those as yet unborn? The dead, it is true, whilst still living and working, were paid for the work actually done, but they have not been paid for those services the effect of which has outlasted their lives and placed the enterprise on a sound foundation; neither have they been paid for the fund of experience which they accumulated and handed down for the benefit of the present generation. And the generations to come, how will they fare? It is to be hoped that they will receive their reward in due time. It is to be hoped! But it is surely better to provide, even now, at least partially for the future. If this line of reasoning be accepted, there remains only the question of how it shall be

realised; to whose care shall be entrusted the rights of the departed, the interests of the generations to come. It will be seen that there exists but one entity which is adequately equipped for the task, and that is the enterprise; not the people for the time being engaged in, and working in it, but the enterprise itself. In other words, the enterprise must be its own proprietor.

And now, let us ask, who are those who are entitled to be considered co-workers and partners in the creation and increase of the wealth represented by the enterprise. In the first place, all those who have been, are now, or, at some future time, will be employed in it; after that, Science, who, as we have seen, was its godmother; and finally the environment amidst which it was planted, nourished, and developed. It is but just, therefore, that the University and town of Jena should participate in the profits of the enterprise.

But it may be objected to this mode of division that it seems to take no account of those who surely are entitled to their share—the persons who have provided the capital by means of which the enterprise was financed. Considered from the point of view of the present economic order, under which the conception of capital bearing interest has governed European civilisation ever since the close of the Middle Ages, it is doubtless true that the people who have provided funds for an undertaking must be numbered amongst those without whom it could neither have been started nor carried on. But after the connection of one proprietor with the business had been terminated in strict accordance with the current economic view, the remaining, and now sole proprietor, who did not recognise the claim of capital to interest, saw fit to carry out his conception to its logical conclusion; to renounce, for his part, all claim to his property, and to entrust to the enterprise, which had already absorbed all other functions, the administration of the capital also.

The statement that the enterprise is its own proprietor is not then strictly accurate, because the business comprises in addition to the Optical Works, a share in the Glass Works. The actual proprietor is the Carl-Zeiss Stiftung already referred to. It owns the Optical Works, and, in partnership with Dr Schott, it owns the Glass Works.

General Rules Governing the Action of the Stiftung.

THE average trust has, as a rule, to contend with simple conditions and to consider two factors only: the capital of the trust and the objects for which it exists. The nature of the trust-fund itself, the manner in which it is rendered productive, and similar questions, have nothing to do with the manner in which it has to be spent. But in the case of the Carl-Zeiss Stiftung the conditions are very different. To provide a large number of people with the most favourable opportunities for labour is both the means and the end of the Stiftung; the individuals who benefit by it are, at the same time, those who maintain and increase it. The officials and workmen employed at the Optical Works, the community, and the University, contribute their share towards the increase of the value of the property, and these, therefore, are entitled to participate in the benefits. Such an intimate reciprocal relationship between means and end demands special regulations, which, in order that they may be neither too narrow nor too wide, must be drafted with the greatest skill.

Let us first consider the general regulations by which the commercial activity of the Stiftung is governed. The commercial field of activity of the Stiftung is strictly limited to that class of industries of which optics, glass technics, and the construction of scientific instruments are the principal representatives. The Stiftung is, however, permitted to engage in any undertaking that may be considered to be subsidiary to these main industries; and there are, moreover, open to it, "related industries,"—a term elastic enough to admit of considerable expansion. The answer to the question, what industries are related to one another, continually varies, and consequently this stipulation makes it possible to take advantage of any change that may occur. The only essential condition is that in the branch of industry chosen, the present intimate relation between technique and science shall be maintained, either in the conditions which govern the manufacture, or in the purpose to which the finished product is applied. Undertakings to which these conditions are inapplicable are excluded, for all time, from the scope of the Stiftung, even for the purposes of investment.

No limits, beyond those already mentioned, are imposed upon

the development of the business; consequently new specialities may be manufactured, and new branches or factories may be started. But these new branches or factories must not be sold, any more than any of the old ones; if for any reason it is no longer thought advisable to carry them on, they must be dissolved. They can be opened and carried on either at home or abroad, but the seat of the main business must never be removed from Jena or its immediate neighbourhood.

The concern is not managed with the same objects as an ordinary business; the end desired is not so much an increase of profits as an increase in the total amount of business done. It is obvious, here again, how end and means go hand in hand; for example, payment of wages is, in an ordinary business, looked upon as a charge only, and is consequently placed to debit only; but, in the case under consideration, it is part of the essential object of the business, and it consequently figures not only on the debit side of the account, but on the credit side also.

A further important question to be considered is, how best to divide the total profits in a just ratio between the two parties who have the principal claims on them, that is to say, between the individuals employed at the Works for the time being, on the one hand, and the Stiftung on the other. The latter is entitled to that part of the total profits which does not result from the organised labour of the workers, either individually or collectively; but must be considered as the outcome of the organisation itself, of the continuous activity due thereto, and of the accumulated results of the efforts of all those whose work preceded that of the present workers. To enable the data requisite for this purpose to be ascertained, a calculation must annually be made to determine what percentage the nett profit bears to the amount paid in wages and salaries. From the total profits must be deducted the percentage amount which, in accordance with the Statutes, has to be placed to the reserve fund. What then remains is the nett profit due to the labour of the present staff. As long as the ratio of the nett profit to the total amount paid in wages and salaries is not less than a fifth of the latter amount and not less than a tenth of the total annual expenditure, all may be assumed to be in order. If, however, this is not the case, "something is rotten in the State of Denmark," at all events in normal times, and the disturbed balance must be restored, either by a reduction of the rate of wages or by some other means. We shall return again to the subject.

Attention must finally be called to one of the ideals of the Stiftung. It is laid down that not only the commercial success of the business belonging to it, but the general advancement of the branches of technics and science with which it is concerned, must always be borne in mind. Consequently it is the duty of the Stiftung, as far as possible, to further any objects of this kind, even if an immediate return is not promised.

The Administration of the Stiftung and the Management of the Works belonging to it.

THE connection between the Carl-Zeiss Stiftung and the Works belonging to it is, theoretically at all events, of a somewhat complicated character; because, whilst it must always be borne in mind that the Stiftung and the Works have separate existences, it must, nevertheless, not be forgotten that they are connected by close personal ties. In practice the relations, of course, work out in a much simpler manner.

The Stiftung is represented, its property managed, and its highest administrative functions exercised by an administrative body—the Stiftung-Administration. Naturally we are curious to know the composition of this body. It was obviously out of the question to appoint an individual, who, no matter how chosen, would, in the last resort, have represented but himself. The sketch of the motives which led to the formation of the Stiftung, as outlined in the last chapter, shows that in the opinion of its founder this would have been jumping out of the frying pan into the fire. An abstract entity had therefore to be found which would not be influenced by the changes and chances of individual life, and whose character would be such that its continued existence might safely be counted upon. Careful consideration led to the conclusion that the object aimed at could only be ensured by vesting the functions in question in some government department, and the scientific character of the undertaking and its intimate relations with the University seemed naturally to point to the

Saxon Grand-Ducal Ministry of Public Worship and Instruction.* The necessity of falling back on the State supplies a further proof, if such were needed, that even he who is least inclined to entrust to the State more than is absolutely necessary may, under certain circumstances, be compelled to avail himself of the continuity and stability represented by it.

The government department referred to appoints one of its own officials to represent it in the Stiftung-Administration. This representative, or Trustee, however, although the highest administrative functions of the Stiftung are vested in him, does not directly exercise any authority whatever; his authority is solely of an indirect character. We may take advantage of this opportunity to correct some wrong impressions, which unfortunately at one time gained considerable credence, respecting the actual character of the Stiftung. The Works themselves are in no wise controlled by the Trustee, but are governed solely and entirely by the Statutes. The whole duty of the Trustee is to see that the provisions of the Statutes are faithfully observed. This circumstance, alone, proves that it is not possible to maintain, as many assert, that the undertaking is under State control. Moreover, the Statutes contain a special provision to the effect that the government department, which, through the Trustee appointed by it, exercises the highest administrative functions of the Stiftung, shall pay, in carrying out any of the duties imposed on it by the Statutes, no more regard to the interests of the State than is legally due from every citizen. And the last remaining uncertainty is removed by a further provision, according to which the representative of the Ministry of Public Worship and Instruction, although he must be chosen from amongst the public officials, nevertheless exercises all his duties in connection with the Stiftung in an unofficial capacity, receives a fixed remuneration for his services, and must be guided in all his actions by the Statutes.

The governing board of the Stiftung comprises, in addition to the Trustee, members of the Boards of Management of the two Works, who sit on these Boards as the delegates of the Stiftung-Administration. The latter appoints to each of the two Boards of Management, in whose hands rests the control of the entire commercial business of the two Works, which are, wholly

*In most of the States which form the German Empire the supervision of education is entrusted to the Ministry of Public Worship and Instruction.

or in part, the property of the Stiftung, two delegates, of whom one acts in his representative capacity only when the other, for any reason whatever, is incapacitated. These persons constitute the close personal connection referred to in the beginning of this chapter, since they are at the same time members of the Stiftung-Administration and of the Boards of the two Works; an arrangement obviously well adapted to prevent even the semblance of a conflict between these two bodies. One other difficulty has, however, still to be faced: it is almost certain that the time will come when the individuals who have to act as members of the Stiftung-Administration and the Works' Boards may not find it easy to give the necessary time and attention to the duties of both positions, especially if the Stiftung continues to extend the scope of its activities so as to embrace objects of a more general nature. Even to-day the supervision of the management of the People's Institute is by no means an easy task; in course of time other duties of a similar nature may have to be undertaken, and it is therefore quite within the bounds of possibility that at some future time a certain separation of these different duties may have to be carried out.

The Boards of Management of the Works consist each of from two to four members; and at least one of the members of the management of the Optical Works must have a seat on the Board of the Glass Works. Membership of the Boards of Management is an honorary office (this, of course, does not apply to the part-proprietor of the Glass Works) and is open only to persons engaged at the Works, who, so far as their administrative duties allow, continue to fulfil the duties of whatever position at the Works they may happen to fill, and do not receive any salary or remuneration whatever for the services rendered in the capacity of Members of the Board. We shall see later on that to a certain extent they are even penalised. Their position does not alter their status as the colleagues of all the other employees; a superior position is only occupied by the Board of Management in its corporate capacity.

Ever since the Statutes acquired legal validity, and until quite recently, the Board of Management of the Optical Works was composed of Messrs. Abbe, Czapski, Max Fischer and Schott. But on the 1st of April, 1903, Prof. Abbe, partly on account of the state of his health, and partly in order to be able to devote himself, as soon as his health should have sufficiently improved, to his scientific work, which had been neglected for a long time past, withdrew from his

position on the Board. The vacancy, thus caused,was filled up by the appointment of Rudolf Straubel. The Board of Management of the Glass Works is formed by the part-proprietor and by a representative of the Stiftung-Administration; but no decision can be carried into effect without the consent of the part-proprietor. A change has already occurred in the personality of the official filling the position of Trustee; Privy Councillor Rothe, the first Trustee, having been appointed first Minister of the Grand Duchy, has been succeeded by Privy Councillor Vollert, one of the heads of the Ministry of Public Worship and Instruction. At present Dr. Czapski is the representative of the Stiftung-Administration on both Boards of Management, Max Fischer acting as his substitute, when required.

The Statutes provide that partnerships similar to that which has existed ever since the foundation of the Stiftung, between it and the part proprietor of the Glass Works, may likewise be entered into in the future; a similar partnership has actually existed in another instance, but has been dissolved. It is, however, distinctly laid down that upon the death of the original partner, or his retirement from active management, his business must become, as far as its representation and management are concerned, the sole property of the Stiftung. No agreement of a nullifying character can be made. The object of this stipulation is, of course, obvious. Whilst there is no objection to a person bringing capital in addition to his ability into the business, it would be out of keeping with the entire spirit of the Statutes to permit capital again to become an independent factor—to again enter, as it were, by a side door after having been turned out by the front.

The Position of the Employees.

TO appreciate the position of the employees of the Jena Works, and the motives which guided Abbe in his action, it is necessary to review for a moment the epoch-making struggle between the skilled handicraftsman and the organisation of the factory system, which has been incessantly waged throughout the last half-century. The small producer, the handicraftsman, even so late as the middle of the 19th century, was, at all events in Germany, almost supreme; but to-day the fight is over, and no one can doubt that organised production on a large scale has given the death-blow to the old method of separate individual production by skilled handicraftsmen. All that the State can do, or ought to do, is to build golden bridges for the vanquished, by means of which they may join the hosts of the victor. All the social conduct of the State, and all the actions of the individual, should tend towards taking the fullest possible advantage of the new economic order of things, whilst at the same time rendering its defects as harmless as may be, and softening its harshness as much as possible. The goal to be reached is revealed to the mental eye of every unprejudiced thinker:—the artisan whose task it is, as the successor and, in the near future, as the sole heir of the skilled handicraftsman of the past, to perform the economic work of the world, must have his economic position so raised, and his legal position so assured, as to constitute him, in spite of the loss of his old-time economic independence, as stable a foundation for the social fabric as the skilled handicraftsman of yore. The work of the reformer must consequently tend towards the development of the laws governing the relations of trade, and those enacted for the protection of the workers, into a real code applicable alike to employer and employee.

It is obvious that there can be no greater contrast than that afforded by this doctrine and another that has been earnestly advocated and carried into practice by eminent legislators; a doctrine which results in what may best be described as "paternal government," and aims at making the modern artisan work under conditions similar to those that governed the labour of the skilled craftsman of the middle ages. In opposition to this latter doctrine, the regulations at Jena are based upon the fundamental assump-

tion that so long as a worker does his duty to the management as a worker, he is at perfect liberty to think, to do, and to leave undone what he chooses. The only obligations imposed on citizens by the State are that they should obey the law. In like manner the duty of the employee is strictly limited to the performance of the labour he has contracted to do. In no other way, either directly or indirectly, does the management interfere with the action or the conduct of any of the employees. An exception, however, is made in the case of boys and apprentices, whose liberty is naturally more restricted. On the other hand, the meaning of the word "work" must not be understood in too narrow a sense. It naturally includes everything that relates to the conditions of employment, as, for instance, the security, order, and care necessary for the successful performance of the work; and in addition to these, it is to be interpreted as imposing obligations on an employee in his intercourse with his superiors, his fellow-workers, and his subordinates. We may mention, that any employee is at full liberty to accept any honorary position in the service of the State or Municipality; leave, on full salary or wage, being granted to enable him to perform the duties of the position. He is, moreover, at liberty to join whatever association he wishes, whether of an economic, social, or political character; and no enquiry is made respecting his political or religious opinions. But the most important of all the rights conceded to the workers is, undoubtedly, the right to combine and to be represented by committees, which not only meet and transact their business in perfect freedom, but also enjoy the right of addressing the Administration on any subject that relates to the affairs of the concern.

It must be admitted that nothing could be more liberal than these regulations. The only question remaining to be considered is how far these conditions of an ideal liberty will stand the test of actual experience; especially when the interests of the Works and those of the individual clash. Let us consider some cases which may possibly arise. It is specially provided that every employee shall be permitted to fill honorary positions; one, for instance, may be elected to the Reichstag, another to the Diet of one of the Federated States; a third one may be chosen to fill a municipal office. What would happen, if one employee should be elected to fill all these positions? Would it be possible for him to retain his place at the Works? As already stated, the Committee of the Works has the right to be consulted on all ques-

tions which concern the management of the Works ; but what would happen if these conferences should become so frequent as to prevent the managers from attending to their ordinary duties? The workers have the right to decline to work overtime ; what would happen, if in consequence of such a refusal the firm should not only lose important orders, but suffer permanent injury ? To all such questions there is but one answer. The liberty is granted by the Statutes on the assumption that it will not be abused, and that the workers themselves will attain such a level that they will be able to fairly balance their own individual interests against the more general interests of the undertaking of which they themselves form a part. The persons holding high positions in the Works do not accept any honorary positions, the duties of which would conflict with those they owe to the Works ; they work overtime, not only voluntarily but gratuitously ; they have reached the higher level of which we have spoken. All that can be expected from the working classes is that they will gradually raise themselves to the same level. It is the principal purpose of the freedom guaranteed by the Statutes, to enable them to learn how that freedom may best be employed.

The preceding remarks relate to the legal rights of the employees. In discussing their economic position, we must distinguish between that of the officials, the time-workers, and the piece-workers. All the officials, including the scientific, technical and commercial staffs, the clerks, and the foremen, have fixed salaries. The great majority of the other employees are paid by the piece, and only a minority by the hour, this minority comprising only those for whom it is impracticable to calculate the wages by the piece. It is noteworthy, that even the piece-worker has a minimum wage calculated on a time basis.*

At first sight there does not appear to be anything remarkable in this, but the case immediately assumes a different aspect when we realise the meaning of the actual figures. Some years ago the average annual earnings of a workman, 24 years of age, and with at least three years' service in the employ of the firm, amounted to £75 ; at the present time it is nearly £80, but it has been as high

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*Shortly after joining the firm, Abbe recognised the desirability of introducing piece-work, and in spite of the strongest opposition of Carl Zeiss and the employees, he succeeded in procuring its adoption. The result has more than justified him. Although the wages for piece-work were, in expectation of the increased output, calculated on a low scale, the workmen were yet able to earn nearly double their former wages.

as £90. As the figures refer to the average earnings it is obvious that there must be many workmen whose yearly earnings amount to between £100 and £150. These wages are much higher than those paid by other similar firms, especially when it is taken into consideration that the business is situated in a small town, where living is cheap. The same cannot, however, be said of the salaries paid to the men occupying a much higher position in the social hierarchy of the business. And this does not result from accident, but is in strict conformity with a proviso, carefully thought out by the founder of the Stiftung, according to which no employee, even though he be a member of the Board of Management, can receive a salary greater than ten times the average yearly earnings of the worker of 24 years of age and over, and with at least three years' service in the employ of the firm. The effect of this proviso is to diminish the rate of increase of the salaries of the more highly-paid employees and officials. At the present time the maximum sum beyond which salaries cannot be increased amounts to £900. It is well known that much higher salaries are often paid by other industrial concerns, and it is a matter open to argument whether it was wise to insist on such a restriction.

It might be argued that an undertaking which, like the one in question, occupies a foremost position in the branch of industry to which it belongs, and which intends to retain that position, owes it to itself always to fill its leading positions with the best men available, even if it be requisite to make material sacrifices for the purpose of securing their services. Human nature must be taken as it is. These are considerations which are surely deserving of the most serious attention, and the founder of the Carl-Zeiss Stiftung did not refuse to consider them. But the all-important factor for him was undoubtedly the social-psychological disadvantages which result, and as experience has shown, must result, when, amongst a number of persons working together, there is one who receives sums out of all proportion to those received by the rest.

It is only in accordance with the spirit that governs the whole constitution of the enterprise that too violent contrasts should not be permitted. In the opinion of the founder the proportion, expressed by the ratio of 1 : 10, is already quite large enough.

The annual income of the employee may, however, be still further increased, as the result of the arrangement treated of in the next chapter.

Profit Sharing.

A SPECIAL chapter must be devoted to this subject, not on account of its intrinsic importance, or because Abbe ascribed special importance to it, but because outsiders have frequently misunderstood its place in the scheme of the organisation; and this seems a suitable opportunity for correcting the misunderstanding.

Many whose knowledge of the social organisation of the Jena Works has been acquired indirectly only, either state without reserve, that the Works belong to the workmen, or they assert that the fact that the workers have a share in the profits constitutes its most characteristic feature. Both statements are false and misleading. In the first place, not only the workmen, but all the employees with one exception, hereafter referred to, participate in the profit-sharing; secondly, profit-sharing does not constitute an essential part of the organisation, but is only of secondary and subordinate importance; and thirdly, whilst it is true that the principle of profit-sharing is accepted in a certain sense by the Statutes and their framer, it is, notwithstanding, true only in a sense quite opposed to that of ordinary usage.

This is not the place to discuss generally the question of profit-sharing. We may, however, just glance at the cardinal points involved, as they were set forth in a lecture by Abbe in the year 1897, before the Social Science Association of Jena. Three kinds of profit-sharing may be distinguished:— (1) That kind of profit-sharing which is intended to lead gradually to the formation of co-operative associations; and toward which the attitude adopted depends largely ou the view held with regard to the question of co-operative associations, i.e., associations in which the workers employed constitute, as a whole, the employer. Experience has, however, shown that an association of this character can succeed only if it does not demand an elaborate organisation, too great a sub-division of labour, or the working together of persons of antagonistic types. (2) That kind of profit-sharing which, introduced for the purpose of ensuring the greatest possible economy of time and machinery, results mainly in an increase of the profits of the employer, of which profits the worker's share is generally an inconsiderable one. It is in fact no more than an imperfect kind of premium system, which, carried to its logical conclusion, leads simply to

piece-work. (3) That kind of profit-sharing which is recommended, amongst others, by Freese as "one of the most effective means for raising the economic position of the working classes, and the best that can be adopted for bringing about improved relations between employers and employed." This looks very pretty on paper, but if looked at in the light of day the illusion vanishes. Under present economic conditions the rate of wages is entirely governed by the law of supply and demand, and consequently, it by no means follows that a share of the profits will produce any addition to the worker's ordinary wage, since its effect is to decrease the rate of wages. The remuneration, as determined by the law of supply and demand, will under the system consist of the sum of the wages and profit, and the worker will find that he has merely surrendered something which, for the time being at any rate, was certain, in exchange for something that is quite uncertain; whilst the employer will secure the advantage of appearing to be actuated by humane and unselfish motives, in voluntarily surrendering to the worker a portion of his profits. Although, as will be seen from this statement of his opinions, Abbe did not look at all favourably on profit-sharing, he has, notwithstanding, provided for it in the Statutes of the Stiftung. He has, it is true, made it permissible only, and not obligatory, but still it is assumed that should the year's business be sufficiently remunerative, a portion of the profits will be divided between the employees. How is this contradiction to be explained? Did Abbe alter his opinion? To arrive at a correct reply we must consider these questions in relation to the present economic order, and more particularly in relation to the present state of the law affecting the rights of labour. The Law does not take account of the rate of wages; but there is no reason why wages should not be regulated by a private statute, and this is exactly what has been done in the Statutes of the Carl-Zeiss Stiftung. When an employee of the Zeiss Works has once reached a certain wage and drawn it for a year, this wage cannot be reduced, even if business should become slack; and, as will be seen further on, it is not practicable, without heavy sacrifice, to reduce it indirectly by discharging the employee. As, however, when trade is brisk it is necessary and just to increase wages, this wage system resembles a ratchet wheel, which having, perchance, been turned too far, or turned when it should have remained stationary, cannot be turned backwards; in like manner, wages once raised cannot

be reduced, and a heavy loss might thus be incurred. The most obvious and certain way of obviating this risk is, of course, to deprive the wheel of its pawl, i.e., to increase wages when trade is brisk, and to reduce them when it is bad. But is there no other less drastic way? Would it not suffice to make use of the ratchet wheel and the pawl, but to interpose somewhere in the mechanism a small free wheel that could be turned in either direction?

In accordance with the considerations just referred to, the Statutes of the Carl-Zeiss Stiftung provide that the remuneration paid to employees, whether salary or wage, shall be composed of two parts:—

1.—A fixed and irreducible amount.

2.—A variable amount depending on the result of the year's trading.

Reconsidering now the entire position, it will be apparent that the feature by which the Zeiss Works is distinguished from businesses carried on under ordinary commercial conditions, is not the adoption of profit-sharing, but the fact that at the Zeiss Works the employees participate in the profits only, whilst at others they share not only in the profits but also in the losses.

It should be stated that the use of the term "profit-sharing" is avoided in the Statutes, and that its place is supplied by the less formal, but more descriptive phrase, "supplementary payment of wages and salaries." All employees—with an exception to be mentioned later—participate in this payment in the same proportion, that is to say, they all receive the same percentage of their annual income. The amount actually paid depends upon the nett profit made, or to be more exact, on the amount which is available after the minimum sum reserved for the Stiftung has been set aside.

This method of dividing the profits appears theoretically to be exceedingly well devised; but human nature being as it is, it does not in practice work out quite in the manner anticipated, more especially as the persons concerned have not yet been sufficiently educated to appreciate fully the advantages to be derived from it, and to subordinate their feelings to their judgment. Men are so apt to view things, not as they are in themselves, but as they affect them, that it is only natural that a worker who has once received a dividend of 10 per cent. should be dissatisfied with one of 5 per cent. only; whilst he is, of course most unreasonably, disposed to consider himself a very ill-used person if some year he receives no dividend at all. And this is exactly what has

occurred. From 1896 to 1902 the supplementary payment varied between 5 per cent, and 10 per cent., with an average of about 9 per cent., that is to say, at approximately an extra month's money per year. When it became known that for the year 1903 there would be no supplementary payment, a considerable number of employees plainly showed that they considered themselves defrauded of their just due. Many of them, having calculated on the certainty of receiving supplementary payment, declared that they were unable to make their usual Christmas purchases, whilst others said that they could not even pay their debts. They ignored the fact that the wages at the Zeiss Works are considerably higher than those paid at other similar establishments, and that the supplementary payments were not intended as regular and annual premiums. An impartial observer, interested solely in the sociological and economic aspect of the subject, can only consider it a fortunate occurrence that, for once, no supplementary payment could be made, as the longer it had continued to be regularly received the more keen would have been the disappointment felt, when it became necessary to interrupt it.

It is, of course, quite another matter to investigate the causes which led to the reduction in the amount, or the total disappearance of the supplementary payment. This investigation is so important and interesting, that some space may well be devoted to it.

It is, of course, easy to say that the fact is sufficiently accounted for by depression of trade. The reply is certainly the most obvious, and in most cases it would undoubtedly be correct. But on the only two occasions when the supplementary payment had either to be reduced or withheld, it was not due to bad trade, as, in consequence of the constantly-increasing variety of its productions, the Zeiss Works has not yet experienced bad times; the true reason was that the wages paid for piece-work were unreasonably high. When the books had been made up, the management, itself, was disappointed at the small amount available for distribution. Judging by the business done, a different result might have been anticipated, and the question arose to what cause the result was due. Upon investigation it came out clearly that it was mainly due to the cause already stated, that is to say, that the amount which should have been available for supplementary payments had already been distributed in the form of excessively high wages for certain kinds of piece-work, to the gain of some of the workers, and to the loss of all the rest. It will be seen, therefore,

that the system of profit-sharing, besides serving its ordinary purpose, performs a subsidiary function, which is of the greatest value to the management; it acts as a kind of a barometer, which shows whether the rate of wages and the general expenses are too high, and if they are it indicates the necessity for a change.

It is now clear that the wages received by a piece-worker can be resolved—not into two, but into the three following parts:—

1.—A time wage, which is fixed and irreducible.

2.—An additional wage for piece-work, the amount of which depends upon the individual.

3.—A supplementary payment, depending on the prosperity of the business.

The only persons who do not participate in the profit-sharing are the members of the Board of Management, that is, the very persons to whom, in ordinary industrial undertakings, special payments are made. The justification for a provision which must at first sight appear strange, is to be found in the circumstance that the Board of Management is the authority to which is entrusted the drawing up of the estimates, together with all their details, such as the determination of the rates of pay for time and piece-work, the amount to be carried to the reserve fund, the payments to be made to the different funds, the selling price of instruments, and the like. The Board of Management is therefore in a position to increase or decrease artificially, within certain limits, the nett profit, on the amount of which depends the sum available for profit-sharing. And if the nett profit were thus artificially increased by a reduction in the rate of pay, for instance, for the purpose of having a larger sum available for distribution among the employees, it might happen that whilst all those receiving fixed salaries, including the members of the Board of Management, would receive increased shares, the sum paid to the wage-earners under the head of profit might be insufficient even to compensate them for the reduction in their wages.

Although the strict logic of this argument might be admitted, the objection may nevertheless be raised, that the Statutes do not apply the ethical principles on which the entire organisation is based to the treatment of the members of the Board of Management. Even the logic itself might be called in question, on the ground that the Statutes provide ample guarantees that the estimates shall not be influenced by considerations of the character referred to. The real interest of the matter does not, however, extend beyond a consideration of the principle involved; as, even should the mem-

bers of the Board of Management participate in the division of the profits, their remuneration would still be much below that paid to people occupying similar positions in other concerns. On the other hand, the members of the Board of Management—at least in theory—participate, equally with the ordinary employees, in the benefits of another provision of the Statutes. This is the provision which authorises a special payment, as an honorarium, in the event of pecuniary advantages accruing to the firm in consequence of exceptional scientific, technical, or economic activity on the part of any employee or worker. One almost feels that such a proviso is really but a concession made to prevailing economic conceptions, becanse Abbe, who has never hesitated to place his entire intelligence at the service of the enterprise, makes, in fact, the same demand of all employees. And it seems somewhat of a contradiction to say: It is your duty to exert yourself to the utmost, but if you do something beyond that, you shall receive a special reward. As things go, however, logic mnst sometimes take account of average hnman nature, which insists that he who secures exceptional advantages for the enterprise for which he works, is entitled to profit by these advantages. In a good many instances, employees have already been allowed to benefit by this proviso, and the same policy will undoubtedly guide the management in the future. The practice has lately been extended in a direction which more especially benefits the worker; rewards have been offered for practicable proposals for the improvement of the business in any respect. These proposals are to be made in writing, identified by a motto only, in the first instance, to ensure their being examined on their merits. These facts are particularly deserving of attention in view of the legend which has grown up respecting the Spartan severity of the Carl-Zeiss Stiftung in matters of this kind.

The Relations between the Proprietors and the Workers.

BEFORE we proceed to matters of detail, let us for a moment consider the real character of the Carl-Zeiss Stiftung and of the Optical Works which it owns. It is not easy to comprehend the true character of an organisation so novel as that devised by Abbe, and it would be as well to view it from various standpoints, before deciding to what extent it differs from other undertakings, and how much it has in common with them. Abbe, himself, on one of the occasions already referred to, with the lucidity characteristic of him, and in language more colloquial than that of the Statutes, attempted to impart to those working under him an accurate conception of the real nature of the community to which they belonged. When it is remembered that even well-educated persons have often, notwithstanding repeated attempts at explanation, obstinately persisted in maintaining totally erroneous views respecting the organisation, it is scarcely a matter for surprise that Abbe was but partially successful in his efforts.

What are the relations that subsist between the Carl-Zeiss Stiftung and its employees, that is to say, between the Stiftung as the manager, representative, and proprietor of the concern, and the entire staff, comprising not only the heads of departments and the scientific collaborators, but also the workers at the vice and lathe? The study of these relations, as outlined in divisions 3, 4 and 6 of the Statutes, makes it clear that the Optical Works are nothing but a productive co-operative society. The Works are owned, not by an individual, not even by a number of individuals, but by a body corporate—the Stiftung. This body corporate, moreover, is not, as in the case of the Board of an ordinary limited liability company, a representative of the interests of invested capital. The capital is in this case provided and increased by the concern itself, although it is true, even if the founder did not say so, that this has become possible only by the aid of a gift. To express it differently: in this instance the capital is not the master, but the servant of labour; the Works belong collectively to all employed in them, subject to the conditions that their proprietary rights are limited to the enjoyment of the benefits of the concern, and that they have no power to assign their interest to others.

What interests, it may be asked, are in the absence of an independent capital represented by the firm? The firm represents the interests of the community as opposed to that of the individual; the permanent as opposed to the temporary interests. The relation existing between it and its employees is similar to that existing between a municipality and its citizens. It has to bear in mind not only the present, not only the now living generation, but the future also, the interests of generations to come. It has especially to regulate the division of profits and to see that whilst the workers receive their due, the firm also receives what is due to it.

The question arises: What persons are to supervise the division of the profits, and at the same time to undertake all the other duties which it is the business of the firm—which after all is but an abstraction—to see carried out? This at once leads to a limitation, or, to be accurate, to a more correct definition of the term productive co-operative society used above. In such associations the usual practice has been that the associates should themselves attend to the matters above referred to, through the medium of an elected board or committee; a mode of procedure that has been shown by experience to be extremely defective. This fortunately is not the case at the Optical Works; we say fortunately, because if it had been, none of the steps which during the last quarter of a century have made the business great would have been taken. There would have been no unity, no proper understanding, no capacity for viewing the parts in relation to the whole. The board of management of such a concern, if it is to be successful, must be independent of the will of the individual members of the society; it must be responsible only to the whole of them collectively. To correctly define the character of the Stiftung, the following limitation must therefore be introduced:—"The Optical Works is a productive co-operative society only with respect to its economic interests and not with regard to its administration and management."

But how is it to be ascertained how much of the annual profit should be divided and how much should be retained as collective property? Generally speaking this is a very difficult problem to solve; but here again Abbe has taught us to differentiate in a remarkably simple manner between these shares. The collective property comprises, first, all that is purely the result of co-operation and of the general organisation; secondly, that which is the outcome of more specialised organisation, of the use of machinery,

and the like; thirdly, all that is due to patent protection, the value of which may be estimated from the amount received for licenses; and to all this must be added everything that cannot be the result of individual labour. This leads to the conclusion that at least a quarter—more correctly, perhaps, a third—of the profits should be reserved as collective property, to be used partly for the purpose of increasing the common wealth, and partly to provide a guarantee fund to meet future obligations.

The Working Day.

THE question of how many hours it is good for a man to labour is not only one of the most important which the science of economics has to answer, but it is closely related to some of the most momentous problems around which rages the battle for social development. The social struggle, like every other, is fought out by two parties occupying opposing camps, and the main question to be decided is: Who are these parties? To this question three different answers are possible. The first and most obvious, and therefore the most superficial reply, is that the conflict lies between employers and employees. The second, which is the reply of the average member of ordinary political parties, is that the parties concerned are, on the one hand, the employers together with those of the workers who are reasonable enough to recognise that their interests are identical with the interests of the employers; and on the other hand, all the workers who are unreasonable and foolish. The third view, which is that on which all Abbe's labours in the field of social re-organisation have been based, maintains that the fight is between all sensible members of both classes on the one side, and all foolish and unreasonable ones on the other. The characteristic feature of this view is, of course, the recognition of the fact that it is only a stupid fiction to assert that whilst there exist both reasonable and unreasonable workers, all the members of the employing class must of necessity be reasonable.

The question we are discussing in this chapter provides a good touchstone for testing the validity of the three positions referred to above. The advocates of the first-mentioned position affect to

believe that it is to the interest of the employer that the working day should be as long as possible, and to the interest of the worker that it should be as short as possible; of course, provided always that the wages do not alter. The employers belonging to the second class, who believe in paternal government, say to their employees: we are quite willing to make sacrifices for your sake, but you must be reasonable and not expect too much. Both these views take it for granted that the interests of the two classes are, of necessity, in conflict. But surely before the validity of this assumption is accepted, it should first be examined and put to the test. Abbe having done so, arrived at the conclusion that it cannot be maintained; that whilst too short a working day injures the employer, and too long a one injures the employee, there exists a golden mean that is equally advantageous to both parties; and that nothing further remains to be done than to determine this mean by scientific methods, and then to regulate the hours of labour in conformity therewith. The right length of working day may vary in different branches of industry; it is not even necessarily the same for the same kind of industry under different circumstances: The weaving industry may, for example, require a longer or shorter day than that of electrical engineering; an industry carried on in a large town, a different one from a like industry located in the country; but it is always possible, scientifically, to determine what length of working day is, under the circumstances, most advantageous to both parties—best for the workers, because it allows them to take proper care of their health, and to recuperate their strength from day to day, and best also for the employers, because the labour of workers in good health is better and more energetic than that of those in poor health, whilst in consequence of the shortened hours of labour a considerable saving is effected in expenditure of power.

In an earlier chapter we have had occasion to state that the enterprise has taken the old proverb: "Rast ich, so rost ich"* as its motto. But there is scarcely a proverb to which there cannot be contrasted another that, fairly interpreted, is just as true. The proverb "Rast ich, so rüst ich"† expresses a meaning which, although quite the opposite of that of the previously

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*Rast ich, so rost ich.—To rest is to rust.

† Rast ich, so rüst ich.—To rest is to prepare.

The reader will observe that the contrast between these proverbs is due to the change of a single vowel. This play on words is, of course, obscured by translation.

quoted one, is equally true. Every reasonable employer should bear in mind the applicability to his workers of the latter proverb, and remember that it is bad policy to mobilise one's troops without leaving them sufficient time to get ready to take the field in good order and readiness for action.

In an address delivered before the Social Science Association of Jena, in 1901, Abbe dealt in an exceedingly clear and able manner, on the basis of his own views and experience, with the problem of the shortening of the working day. So much of this address as can be repeated within the space available is here briefly summarised:—In the early part of the year 1900, the employees of the Optical Works were asked to say whether they thought themselves capable of, and were willing to do, as much work in eight hours as they had heretofore done in nine. Six-sevenths of the replies were in the affirmative; and as a consequence the working day was reduced, at first tentatively, for a year, to eight hours. The result was satisfactory in the highest degree. An accurate comparison of the work done before and after the change could, for various reasons, be made only in the case of 233 piece-workers. It was, however, found that in this instance the output, so far from having diminished, had actually increased by 4 per cent.; or, to put it in another way, the hourly rate of pay, which to enable the worker to earn the same as heretofore should have increased by 12 per cent., had in fact risen by 16 per cent. Notwithstanding that the conditions of work vary very considerably, the above result was found to be applicable to workers of all ages, and, with perhaps a single exception, to every department. At the same time the efficiency of the machinery was considerably increased.

Still more interesting than the results of this statistical investigation were those of a psychological enquiry, which was carried out secretly, and which supplied evidence, the value of which was all the greater because the results in question, objectively considered, were in opposition to the subjective feelings of the people concerned, and could not therefore have been influenced thereby. The workmen, when asked, invariably declared that in order to avoid loss they had worked very hard at first, after the introduction of the eight-hours day, but that they had been unable to keep up the pressure, and had fallen back into the old routine. They therefore wished to return to the nine-hours day, as otherwise their position would be very unfavourably affected. The records, however, showed that whilst it was undoubtedly true that the workers had laboured for the first few

days under abnormally high pressure and had then slowed down, they had, notwithstanding, ultimately accommodated themselves—not, as they imagined, to the former hourly, but to the former daily output, doing in fact a little in excess of this. This shows that work under increased pressure, so long as the pressure is not so great as to lead to an increase in the daily output, does not produce over-exertion.

What is the explanation of this remarkable objective and subjective result? It is true, as experiments carried out in England more especially have proved, of all kinds of work, not necessarily, of course, with reference to the same number of hours as in this case. The explanation must, therefore, be of general application, and must be sought in the constitution of the human character. It is at this point that Abbe rounds off his statistical-psychological structure with a law, as simple as it is original. He presents this law in the form of a mathematical equation, which postulates that just as man to avoid financial bankruptcy, must balance his income and his expenditure, so in like manner, to avoid bodily exhaustion, he must balance his physical forces. As "many a mickle makes a muckle," so if he expends energy at a greater rate than he can recuperate, no matter how small the excess of expenditure, he must sooner or later break down. Abbe's law consequently states that the energy expended daily must not exceed that stored up, or to express it in more popular language, that the recuperation must be equal to the fatigue. The equational form of this law is obviously that F must be equal to R, where F and R, respectively, denote fatigue and recuperation. This equation expresses the condition which must be satisfied in order that a given physiological effort shall result in the maximum yield of work. Expressed in this vague and general manner, it may not signify very much, but it becomes a matter of vital importance as soon as it is recognised that the two quantities F and R have a precise scientific and psychological value, and that they can by suitable analysis be expressed in terms of their fundamental units. Fatigue results from the using up of material indispensable to the maintenance of the organism, and from the accumulation in the organism of substances which are prejudicial and in the long-run poisonous. The recuperative process is the exact converse of this. And to make the result of the one process equal to that of the other it is necessary for R to be equal to F.

The quantity F, that is to say, Fatigue, can be resolved into three distinct parts. The first of these is represented by the daily

output, the second by the rate at which the work is performed, and the third, which is for our purpose the most important, by the exhaustion which results in pauses in the work—the time occupied in standing or sitting idle, in consequence of the noise, worry, and the comparatively bad air of the workshop. These short interruptions of work, lasting in each case only a few seconds, or at most a few minutes, cannot be considered as the equivalent of an interval of rest equal to their sum; on the contrary, instead of counteracting the fatigue due to the actual work, they necessarily make a further contribution thereto. This part of F is clearly analogous to the idle running of an engine, and may therefore be called the idle running of the worker.

It is now obvious that Abbe's equation points to the following conclusion:—The working day may be reduced to such a degree that the exhaustion due to the increased pressure under which the work has to be carried on is balanced by the increase of recuperation due to the increased leisure, and the reduction of the idle running. In this way the length of the most effective working day may be determined. It is obvious that this length must vary in different industries, both in consequence of the variation in the difficulties and the character of the work itself, and on account of the wide limits in the rate at which it is performed, which depends not only on the labourer himself, but on the machinery, and other circumstances. The more delicate the character of the work, and the more the rate at which it can be performed is under the control of the workman, the shorter will be the most advantageous working day. The experience accumulated at Zeiss', as well as at other Works, has shown that a large proportion of the industrial population does not work at the maximum of efficiency when working nine hours a day, but does so when the day is reduced to eight hours. It has been shown in many cases that the introduction of an eight-hours day is scientifically justified, because it has been proved to be the most advantageous arrangement for both parties concerned, for the firm as well as for the workers. Whilst the efficiency of the workers has been maintained, the firm has avoided expenses which would otherwise have had to be incurred.

It is impossible here further to discuss this interesting problem; two points, however, must be briefly referred to. It has already been stated that the output of the piece-workers was not diminished, but rather increased, in consequence of the reduction of the working hours. In the case of workers paid by time, only an indirect estimate, based on the output of machinery, can be made, and if that is done it is found that in this case also no appreciable

diminution can be detected. It must, however, be admitted that in the case of time-workers, the result is by no means as favourable as in the case of piece-workers—a result that might under the circumstances have been anticipated. The shortening of the working day must consequently tend to extend, as much as possible, the system of piece-work, and in the opinion of those who declare that "piece-work is killing work," this is a factor which must militate against the advantages of a shorter working day.

But even if it is thought that the saying just quoted may have some justification, Abbe's investigation clearly shows that it is not justifiable to base on it an argument against reducing the length of the working day. Piece-work, if carried on under too high pressure, is, it is true, killing work, and does harm to the individual, whose only thought and care is to turn out as much work as possible; but, as we have seen, this condition does not arise at all, because the worker so easily accommodates himself to doing more work in less time, that he entirely loses his appreciation of the fact. Consequently, however justifiable it may be under some circumstances, the saying ceases to be applicable as soon as a working day of the right length has been adopted.

The second point to be dealt with relates to the increased leisure resulting from the reduction of the working day, and to the question as to how the worker should spend his time. Generally speaking, the employer has no concern with this question, provided the worker does not so employ his leisure as to counteract the advantages to be derived from the shortening of the working day. It is his duty, during his leisure hours, to give sufficient rest to those bodily and mental functions which are active during his employment; and a regulation to that effect has actually been introduced at Jena. So long as this is done it is a matter of no concern to the management as to how the worker occupies his leisure time. The individual is sure to find some suitable occupation in the nature of a change to his regular work, according to his tastes and capacity; his family, home and garden are certain to afford suggestions. And if it be argued that increase of leisure goes hand in hand with an increased opportunity for abusing it, it may be replied that a worker who elects to fritter away his leisure time in questionable pursuits will generally do so, no matter whether the time at his disposal is an hour more or less. At all events a great step in advance should not be withheld on account of possible injury to a small proportion of the people it is desired to benefit, due to their misuse of the opportunities provided.

In consequence of the success of this experiment, the eight-hours day was finally introduced on the first of April, 1901. In contrast with the practice observed in some Berlin concerns, the working day at Jena is divided into two periods, so as to allow from $1\frac{1}{2}$ to 2 hours for dinner, a suitable arrangement for a small town. The working hours extend in summer from seven in the morning, to half-past eleven o'clock, and in the afternoon, from half-past one to five o'clock; in winter from eight to twelve o'clock, and from half-past one to half-past five o'clock. Overtime is only allowed under exceptional conditions, and must be correspondingly paid for; on the other hand, however, if the workers are put on short time, which can occur only under very exceptional circumstances, no deduction is made from the full wage.

And now, before proceeding to a different branch of the subject, we must say a few words on a matter which apparently, at first sight, has no connection with anything with which we have dealt. The circumstance that on the first of May, work at the Jena Works was stopped at eleven o'clock, caused a great sensation in Germany, and was denounced by many as a capitulation to the demands of Social Democracy. No one who attended the memorable meeting at which Abbe delivered the lecture on the eight-hours day to which we have referred, can share this view. In this lecture Abbe explained, with the scientific reserve demanded by the subject, his theory of the physiological equivalent of labour and the right length of the working day, and gave the results of the experimental testing of the theory, as carried out at the place he himself was connected with. And then, in a peroration spoken with a voice which showed how near the subject was to the speaker's heart, he referred to the conditions of bygone times. He began with a description of the infamous conditions under which people worked for 13 and 15 hours a day, even so late as the middle of the 19th century. He referred to the ever-memorable Bill for restricting the working hours of women, which was introduced to the British House of Commons in 1846—a Bill that inspired Macaulay's celebrated oration, and the acceptance of which, when it did occur,* marked the first sign of better times. And the day on which the first dawn of social progress gladdened the hearts of the workers, fell on the 1st of May.

* The "Factory Limitation Act," which limited the working hours of women and young persons to ten hours a day and fifty-eight hours a week, was passed in 1847, and took full effect from May 1st, 1848. A similar bill had been rejected, on the second reading, in 1846, by 203 votes to 193. It was during the debate that led up to this rejection, that Macaulay delivered his famous speech. [Trs.]

Provision for the Welfare of Employees.

IN this chapter we intend to enumerate some of the many arrangements made by the firm for the welfare of the employees. It need scarcely be stated that the origin of most of these provisions dates back to a period anterior to the foundation of the Stiftung, and that the Statutes only codified and extended them.

(*a*) HOLIDAYS GRANTED TO WAGE-EARNERS.—When every official enjoys an annual holiday, during which he continues to receive his salary, it is only fair that the same privilege should be extended to the workmen. On the other hand, it cannot be expected that they should be paid the full amount they would earn by piece-work, as that is calculated on the basis of a minimum time-wage, to which is added a supplementary wage for special industry, skill and capability. As a matter of fact, then, every workman is granted six days' holiday in the year, during which he receives the standard time-wage. Of course, the workers, with the concurrence of the management, have to make suitable arrangements among themselves for distributing over the whole year the time during which the holidays are taken, so as not to interfere with the routine of the business. No difficulty has as yet arisen in doing this.

(*b*) SICK-FUND.—The first sick-fund in connection with the Optical Works dates back to 1876, when the firm employed about 60 workmen. The fund was supported by the regular contributions of its members, and by occasional gifts from the firm. In 1884 its character was changed, to a certain extent, with the object of making it conform with the law, and it assumed the name "Industrial Sick-fund." The amount of the sick pay was fixed for the first six months at three-fourths of the wages normally earned; for a further three months its amount depended on circumstances. The members were free to choose their own medical men. The contributions of the members amounted to 1·2 per cent. of their standard wage, the firm itself contributing a further 0·6 per cent. In 1892 the amount of the contribution was increased to 3 2 per cent. of the standard wage, the additional income thus obtained being used for allowing the families of the workers to participate in the benefits of the fund. The firm then undertook to contribute a sum equal to half the amount of the total contributions,

without exercising its legal right of interfering with the management of the fund. It only reserved to itself a veto against any proposal to dissolve the fund, to change its constitution, or to alter the amount of its contributions.

(*c*) PENSION STATUTE.—The arrangements made by the firm to insure the material welfare of its employees in cases of old age or incapacity for work, date back to a period long anterior to the time when these matters were regulated by law. The pension statute was issued on the day of the death of Carl Zeiss, and therefore dates back to the year 1888. The benefits which the workers derive under it greatly exceed anything demanded by law, not merely with respect to the amounts to which the workers themselves are entitled, but more especially on account of the fact that their families also participate in them. The Statutes of the Stiftung provide that under certain circumstances the provisions of the pension statute should become still more favourable to the workers. As these conditions have since been fulfilled, the rules at present in force provide as follows:—

Every employee, clerk, or workman who, before completing his 40th year, enters either of the Works belonging to the Stiftung, is entitled, after five years' service, to a pension for himself, in case of his being incapacitated for work by disease or age; whilst in the event of his death, his widow and orphans become entitled to pensions. These claims are enforceable at law. Time spent in the service of the firm by an employee, whilst under the age of eighteen years, does not count for a pension. The calculation of the pension is based upon the monthly earnings, so long as they do not exceed, for workers with five, ten, and fifteen years' service, £5, £6, and £7 respectively; the maximum monthly earnings for foremen, counting-house and other clerks, under like circumstances, being £6, £8 and £10 respectively. Any employee who has been from five to fifteen years in the service of the Stiftung is entitled to a pension amounting to 50 per cent of his income, determined under the limitations referred to above. For each subsequent year of service his pension is increased by 1 per cent. of his salary, so that at the end of forty years' service it amounts to 75 per cent. of his income—the maximum percentage given. If upon attaining the age of sixty-five, he has been in the employ of the firm for thirty years or over, he is entitled to a pension of 75 per cent. of his income. Finally, the widow of an employee is entitled to 40 per cent., and each of his orphans to 20 per cent. of the pension to which the husband or

father would have been entitled; the total amount receivable by a family being, however, limited to 80 per cent. of the pension.

The payment of the large sums, which may become due under this scheme, is guaranteed by the establishtment of a special reserve fund, the total amount of which is increased annually in a definite proportion to the profits of the business. To provide, moreover, against the contingency that the demands on the fund might increase to such an extent as to cripple its capacity, it has been thought well to make the employces contribute at a very moderate rate towards a Widows' and Orphans' Fund. But no contributions are asked for—nor, under the Statutes, can be demanded—towards the insuring of the employees themselves.

The Statutes further stipulate that employees "entitled to a pension and who have become invalided, or partly or wholly incapacitated by disease, or by any other cause not due to their own gross negligence," can only be dismissed by the payment of that pension. This provision makes it impossible, lawfully, to dismiss an employee, whose health has become precarious, with the object of saving his pension; an event, moreover, already provided against by the Statutes of the Stiftung.

(*d*) COMPENSATION IN CASE OF DISMISSAL.—One of the most idealistic demands made by the representatives of the working classes in the constant struggle for emancipation, is undoubtedly the one epitomised by the words: "the right to work." It is idealistic both in the sense that it is impossible to doubt the high ethical justification of the principle embodied in the demand, and in the sense that its realisation appears to be, even if not actually impossible, at all events exceedingly difficult. But as long as the State is not in a position to take steps to bring the demand nearer to realisation, it remains the duty of private employers to remove, at least the worst of the evils inseparable from the present system. The first and perhaps the greatest evil to be fought against is the practice, which in consequence of increased industrial activity and the spread of business due to the inventive spirit of the age, has in recent years shown a constant tendency to increase, of arbitrarily engaging and dismissing large numbers of workers who are first tempted by the offer of high wages to leave more modestly paid but certain employment, and are then turned adrift as soon as the first rush of the new business is over and things begin again to steady down. Recognising that by such a policy a large unemployed proletariat is, so to speak, artificially bred, and that the practice in question must in many instances lead to over-produc-

tion and its attendant evils, the founder of the Carl-Zeiss Stiftung has included in its Statutes a provision which will, probably, for some time to come, make it difficult to increase the number of employees. In accordance with this provision any employee, who, after being employed for three years or more, receives notice of dismissal for no fault of his own, is entitled to a payment in compensation, the amount of which must be at least equal to half his yearly salary or wage, and to a quarter of the pension to which his length of service has entitled him; whilst in the case of an employee who has not served so long, this payment is, of course, proportionately less.

The payment of compensation for discharge represents, as it were, a kind of insurance against loss of work, by providing the discharged workman with the means of temporarily tiding over a bad time, and securing him leisure to seek other suitable employment.

The scale, in accordance with which compensation is allowed, is so liberal, that any undertaking adopting it, which constantly changes its employees, would soon find itself on the verge of bankruptcy. At the Jena Works its main function is to serve as a barrier against any imprudent increase in the number of people employed. Only one occasion has so far arisen on which it has been necessary to pay any considerable amount as compensation. On the first of October, 1903, it became necessary for special and somewhat complicated reasons to discharge 60 workmen. A sum of more than £1,500 was paid to them as compensation.

(*e*) MINOR PROVISIONS.—In conclusion, we can but glance briefly at some of the numerous minor provisions for the welfare of the employees, many of them quite without precedent in industrial undertakings. Amongst them are the following:—

Payment of wages for all holidays not falling on a Sunday: two or three days at Christmas, two days at Easter and at Whitsuntide, Good Friday, Ascension Day, Day of Humiliation, and New Year's Day. These holidays amount in the total to ten or eleven days, so that the payments received for them are equivalent to an increase of income of about 3 per cent.

A savings bank, into which each worker can put a portion of his earnings amounting to £50 annually, and for which he receives 5 per cent. interest; a much higher rate than that paid by other savings banks. The fact, moreover, that the savings bank, by its convenience, encourages the worker to save, must not be lost sight of.

Wedding presents and presents given to celebrate length of service.

Grants of money to assist the employees in becoming possessed of homes. (We shall refer later to the Building Society.)

Considerable annual grants to continuation schools, as well as sums paid for special courses in subjects, a thorough acquaintance with which is of service to the employee.

Food supplied to juvenile workers free, and at reduced prices.

Since the autumn of 1892, periodical medical examinations of juvenile workers, for the purpose of preventing the spread of, or predisposition to, certain diseases, to which young people are specially liable. This arrangement, which is absolutely without precedent, has proved extremely beneficial, and has undoubtedly in many cases preserved health and saved life.

BATHS.—Ordinary cold baths, Russian vapour baths, shower baths and massage. The baths are open during the whole 8 hours of the working day; each workman is allowed half an hour weekly for a bath; everything is free. About 40,000 baths are annually taken.

Some other institutions connected with the Works, the benefits of which are not limited to the workers, will be described in a later chapter.

The Patent Question.

THE full significance of the growth of the Jena Works which, at all events in the field of practical optics, has been without precedent, cannot fairly be estimated unless another most important factor be taken into account. It is often asserted that an industry cannot be created, or its development assured, unless extensive and effective measures are taken for the protection of its productions, as by the taking out of patents and the imposition of protective duties. The Zeiss Works, however, afford a splendid example to the contrary. Their experience incontestably proves that a new undertaking can gain a prominent position in the industrial world without such adventitious aids. The protective duties levied on the productions of optical and mechanical workshops have never amounted to much. Within recent years the German Association

for Optics and Mechanics, influenced no doubt to a considerable extent by the teaching of Abbe, has expressed itself to the effect that these duties should not be increased, and that any success achieved should have for its foundation the excellence of the instruments produced.

The position maintained at Jena with reference to the patent question is especially worthy of attention. For forty years the business was carried on without any patent protection whatever for the products of its skill; yet in spite of this the apparatus made at Jena had been able to gain a reputation greater than that of the productions of any other firm, a reputation entirely due to the high degree of perfection attained. It is in view of this fact that the Statutes decree, for all time, that others shall not be prevented, by patents or otherwise, from making any instrument or apparatus designed at Jena, of which the main purpose is that of study or scientific research.

A different course is pursued with reference to instruments or apparatus for more general purposes. The question of patenting such instruments arose, for the first time, in connection with the invention of the anastigmat. On consideration, it had to be admitted that unless the firm reserved to itself the right of making the lens, not only its own business, but even the commonwealth would suffer an injury, for which the maintenance of the ethical principle involved would not afford sufficient compensation. Two possibilities had to be taken into account. Rival firms would either manufacture the lens more cheaply, and consequently of inferior quality, in which case the public would soon begin to under-estimate the intrinsic value of the principle underlying its design; or they would turn out work equal to that turned out at Jena, in which case, as many would have to share in the profits derived from the manufacture of the lens, the price would rise, and the public would consequently derive no advantage from the fact that it had not to pay for patents. Further, it had to be taken into account that whilst the Stiftung is under an obligation to study the interests of the representatives of science, to whom its existence is due, it is under no such obligation to the general public, which, consequently, therefore, can only be considered after the Stiftung has discharged its duties to its employees, for the benefit of whom it exists. That the interests of the latter suffer when the enterprise is deprived of a source of income is sufficiently obvious.

In practice, however, things are not quite so simple. The state

of affairs is unfortunately such that the taking out of patents must be looked upon as a necessary and unavoidable evil; for not only does each patent application involve a good deal of labour, mostly unproductive, but a patent specification is very liable to lead to a law-suit, more especially when a critical appreciation of the subject matter in dispute necessitates the most delicate differentiation of work based on highly-specialised knowledge. Who, in such cases, can expect a Patent Office, or even a Court of Law, to arrive invariably at the truth? And to be defeated in such a suit is painful and discouraging to the man who is convinced that he is right, and more especially so to the man who works, not for himself so much as for his fellows. And even in those cases in which the decision is undoubtedly right in the eyes of the law, that is to say, in which, according to the state of the law, there can be no doubt that a claim for a patent cannot be maintained, the decision may, nevertheless, not be in harmony with one's innate sense of justice. Is it, for instance, possible to feel that the refusal of the German Patent Office to grant a patent for the prism combination, used in the construction of prismatic field-glasses and telescopes, was justified by the fact that a paper anticipation, forty years old, was found? This invention was independently made at Jena, and the alleged anticipation had all this while lain dormant and barren of results. Can it be considered just that now, after the discovery of its actual value has been made, all the makers of optical instruments should be allowed to participate in the profits of an invention to which not one of them had ever before given a thought? So little was the matter thought of, that one is justified in stating that what is actually manufactured to-day, is not Porro's but Abbe's prism combination.

But such is the way of the world. Of every new and beneficial institution—and the system of granting patents, undoubtedly, belongs to this class—it can be said as of an engine, that it never produces more than a fraction of the results it is theoretically capable of. And we must be contented if the fraction has a positive value.

The Patent department of Carl Zeiss, and Schott & Genossen is under the control of an engineer, Mr. Dönitz. The legal interests of both Firms are looked after by Dr. Paul Fischer, a solicitor.

University Subsidies.

THE course of development in every branch of human activity has, during recent years, made it increasingly difficult for the small man, or the minor state, to hold its own. Evidences of the truth of this statement meet us on every side, not only in trade and commerce, but also in the different branches of state administration. The general expenses of a minor state are relatively much heavier than those of a larger one. A minor state, wishing to keep up a University, is in a difficult position. The Saxon Duchies, which have been formed out of the lands of the former Electorate of Saxony, number barely one million inhabitants, whilst the Prussian Rhine province has between five and six millions. It is obvious, therefore, that the Duchy cannot possibly spend as much public money on the University of Jena as the Prussian Government can spend on the University of Bonn. And if it were not for the large sums of money the Thüringian University receives from private sources, there is little doubt that it could not continue to meet and satisfy the large demands nowadays made on a University. Amongst the subsidies it receives, by far the greatest are those paid by the Carl-Zeiss Stiftung, and it may safely be asserted that no other German University, or scientific enterprise, receives from a private source amounts approaching those paid by the Stiftung to the University of Jena.

The sums of money placed at the disposal of the University, by the Carl-Zeiss Stiftung, may be divided into two classes:—(1) Regular periodical payments, made in accordance with a given scale, and paid into a separate fund, termed the University Fund of the Carl-Zeiss Stiftung, and (2) extraordinary or occasional payments. The first are devoted to the maintenance and extension of scientific institutions connected with the University, and to the payment of the salaries of a number of the professors; the second are intended to supply the funds for specific objects. The condition was at first imposed that the money should be spent only in the advancement of physical science, and more especially of those branches which are more closely connected with the enterprise conducted by the Stiftung; but latterly a modification in the Statutes of the Stiftung has been made, which allows the money, or a part of it, to be expended for the general purposes of the University. To mention a few instances: Money provided

by the Stiftung has been used within the last few years to carry out the extension of the chemical laboratory, and to build new laboratories for physics and hygiene; whilst a new mineralogical institute is nearly finished. The two most important additions to the University of Jena, due to the initiative of the Carl-Zeiss Stiftung, are, however, the Physico-technical and the Chemico-technical Institutes, in which the students of to-day—the teachers of to-morrow—are given an opportunity of becoming intimately acquainted with the principal processes of physical and chemical technology. These institutes, to the erection of which Otto Schott has largely contributed from his private purse, have made Jena the equal of Göttingen, and the superior of every other German University, not one of which can boast the possession of an equivalent of either institute. The opportunities they afford are of the greatest value even to those who, for any reason, may during their course of study decide to take up physical and chemical technology, instead of devoting themselves to teaching. A further improvement, due to the initiative of the Carl-Zeiss Stiftung, and which could not have been effected without its assistance, has been the re-adjustment of the salaries of the University professors. To this we shall again recur. The largest grant yet made will shortly result in the erection of a university building, which will satisfy all modern requirements. The total amount of the sums granted by the Stiftung to the University already far exceeds £50,000, and will shortly have reached £100,000.

The People's Institute.

IT is by no means easy to discover suitable words in which adequately to describe the spirit which permeates the rules laid down by the Statutes of the Stiftung with respect to the spending of that part of the surplus which is not devoted to the benefit of its employees. It would be easy enough to speak of it as "democratic," but if that is done we would have to add that the word is used, not in its ordinary one-sided sense, as referring to a particular class, but in its broader and more comprehensive one, as including all classes of the population. It was not the intention of the framer of the Statutes to show preference for one class more than another, and if it seems, in spite of all this, that

Fig. 80. The People's Institute.

the so-called lower orders, the working class, enjoy some advantages, this is due solely to the fact that this class has heretofore been neglected to such an extent, that its needs are so much greater than those of the more fortunate members of the population.

Keeping this point in view, and leaving out of consideration, for the moment, the grants for University purposes, it will be found that the Statutes distinctly ordain that the funds of the Stiftung shall be so spent as to benefit all classes, and not one class only. They consequently direct that no account shall be

Fig. 81. Reading Room.

taken of religious or political opinions, or of social position. This direction has been strictly borne in mind in all undertakings for which the Stiftung has been responsible, and it is the guiding principle in the management of the People's Institute, an institution which may justly be considered the glory of Jena. On passing from the building, in which the Board of Management of the Optical Works is housed, to the Carl-Zeiss Platz, we see in front of us an imposing building, planned and decorated in a severe but impressive manner in the German Renaissance style. This building is the People's Institute, built by the Carl-Zeiss Stiftung, at a cost of nearly £50,000. It contains the Schaeffer Museum, a library and public reading room, a museum of literature, a technical school, a large hall for meetings and festivities, two lecture halls, an art gallery, ateliers for artists and amateur

photographers, a music room, and rooms for other similar purposes.

The Reading-Room Association, which was founded some years ago, and was at first housed in hired rooms, has since been provided with a home of its own in the new building. The greater part of the current expenses of the Association is met by grants from the Stiftung, whilst a smaller part is met by the contributions of ordinary and extraordinary members. There are no other sources of iucome; the use of the rooms is free to everyone, and contributions from visitors are quite voluntary. And although Jena, in spite of its 25,000 inhabitants, is after all only a small town, its library is, notwithstanding, the best, most modern, and most comfortable of all the public libraries in the German Empire. It provides for the use of its visitors more newspapers, periodicals, and pamphlets than any other German library, and it is visited by a relatively larger number than any other.

The 100 political newspapers, which are at everyone's disposal, represent all shades of public opinion; even social-democratic papers are placed on the table, a circumstance which has caused a great deal of discussion, but for reasons already stated, no notice has been taken of that. Every visitor to the library will find what he requires, and besides, it is obviously illogical to assume that one desires to read only the productions of his own party press; on the contrary, the reading room offers to him, who reads at home the organ of his own particular party, the chance of extending his mental horizon, and of forming an unbiassed opinion by providing him with an opportunity of becoming acquainted with the views held by others. In fact, people of all classes—the professor and the student, the man of means and the worker—meet harmoniously at the library.

A large hall on the ground-floor contains newspapers; a similar one on the first floor, periodicals of every kind, nearly 300 in number; whilst another room contains patent publications, works of reference, and pamphlets discussing the questions of the day from every possible standpoint.

Connected with the reading rooms is a lending library, that issues annually, to the inhabitants of Jena and the neighbourhood, over 100,000 volumes. The books lent out belong to every department of literature. An observer watching the stream of borrowers will notice that working people and agricultural labourers furnish a large proportion of the readers. Amongst them are persons who, at first, find it necessary to request the offi-

cials to recommend books to them, but the majority of these soon become able to choose for themselves. The technical school and the Schaeffer Museum are also housed in this wing of the building. The Schaeffer Museum contains a collection of simple, but at the same time highly instructive physical apparatus, suitable for use in elementary education. This collection was made by the late Professor Schaeffer, and was bought after his death by the Carl-Zeiss Stiftung. It is especially valuable in connection with the lectures by means of which the younger employees of the Optical Works are provided with an opportunity for continuing their studies.

The part of the building with which we have been dealing forms the left wing of the whole structure. It is connected with the right wing by a smaller central building, which, amongst other rooms, contains a small hall with sitting accommodation for 200 people. A single glance at the paintings which decorate this hall will suffice to inform us that they are from the hand of an artist of the modern school. They are the work of Erich Kuithan, who was specially brought to Jena by the Stiftung to assist by his work and teaching in raising the artistic appreciation of the beautiful, not only amongst the people connected with the Works, but amongst the general population—an action which shows how seriously the Stiftung takes its mission of raising the level of culture.

Besides a number of rooms devoted to the art gallery, the right wing contains the largest public hall in Jena, capable of seating about 1,400 people, and numerous smaller rooms connected with it. The large hall is principally intended for meetings of the staffs of the Optical Works and Glass Works, which, although nearly 2,000 in number, have hitherto been without a meeting place. It is further intended for meetings, assemblies and festivities of every kind. Since, as need scarcely be stated, the hall is at the disposal of every party without distinction, it is in the nature of things that the social democratic party derives the main advantage from its existence; but this is, after all, only due to the fact that the disadvantages of being unable to procure without difficulty a suitable place for holding its meetings, has by the building of the hall at last been overcome.

Other Grants to Public Institutions.

THE People's Institute occupies such a unique position, in Germany at least, that the detail in which we have described it is pardonable. This has, however, rendered it necessary that we should refer but briefly to the numerous other institutions formed and supported, wholly or in part, by the Stiftung. The most important of these are as follows:—

THE JENA BUILDING SOCIETY.—There cannot be many places where the demand for small dwellings has been more pressing than in rapidly-growing Jena, where the Optical Works and the Glass Works, the railway workshop, and a large number of other industrial undertakings are alone responsible for an annual increase of population amounting to from six to eight per cent. The fact that this demand has been largely satisfied is due to the existence of the Jena Building Society, which, founded in 1896, has not only provided nearly 200 cheap and comfortable homes, but has set an example which private builders have followed, and has likewise done not a little to bring about an improvement in the condition of the already existing houses. Although the Building Society carries on its work by means of the contributions of its own members, it would scarcely have been possible to start it on a sound basis without outside financial assistance, and especially without that afforded by the Carl-Zeiss Stiftung, which subscribed £750, as a free gift, and advanced an equal amount at the low rate of interest of three per cent.

The popular courses of instruction and evening meetings, arranged by the Comenius Society, are largely supported by the firms of Carl Zeiss and Schott & Genossen.

Grants have, moreover, been made by the Stiftung to the Hospital for Consumptives, known as the Sophienheilstätte, at Berka, on the Ilm; the Children's Home at Jena; the Club Frauenwohl; the Public River Baths at Jena and Wenigenjena, and to many like institutions.

Finally, we must again mention the relations between the Stiftung and the University, with special reference to the re-arrangement of the salaries of the professors; a subject of which we have already spoken in an earlier chapter. It was largely due to the co-operation of the Stiftung that an end was put to a condition of things which for long had been a crying evil. Until recently

the salaries of the Jena University professors were of very modest amounts—much lower than those paid at other German Universities. The professors, however, as a compensation, enjoyed freedom from taxation. It is obvious that whilst this might be a matter of considerable importance to a rich man, it could not afford any substantial relief to the man of small means. The system, therefore, was one which not only unduly favoured the rich, but placed the whole body of University professors, morally and socially, in a position which, as compared with that of the rest of the citizens, was by no means an enviable one. But it was a system which seemed almost to have been created for the express purpose of realising, with the assistance of the Stiftung, Abbe's ideas. This was done. The privilege of freedom from taxation has been abolished, and the remuneration of the professorial body arranged on a more satisfactory basis. It redounds to the credit of Abbe that before providing the means which enabled this to be done, he insisted upon the acceptance of two conditions, the outcome of the spirit of tolerance and liberality of thought which characterises all his actions. The two conditions on which Abbe insisted were, that neither the liberty to teach, nor the intellectual freedom of the teachers, should be interfered with under any circumstances; and further, that the University Institutions should, as far as practicable, be used for popular instruction also.

Our work is done. In the preceding pages we have tried to describe a most unique and characteristic enterprise; an enterprise which bears in all its aspects the stamp of a close and intimate union of Idealism and Realism, and which has succeeded in less than fifty years in gaining for itself a leading position in the industrial world, and in entirely changing the character of its immediate environment. The one-time quaint and unpretentious University town has become a hive of industry, throbbing with life and activity. Whilst the majority of its inhabitants, as is only natural, rejoice in the change, there are others who, perhaps quite as naturally, do not share in this satisfaction, but look back with sorrow and regret upon the change which has come o'er the scene. What, they say, would the great men of the past, he above all others, of whom Jena is so proud, who so often spoke with delight of the "dear foolish little town," have said to this "degradation"? His greatest work supplies the answer to this question. The Jena of the past was the first Faust, the Faust of the study; the Jena of tbe present is the second Faust

—plunged in the realities of existence, vigorously and strenuously helping to raise up the great dyke against the ocean of misery and vice which threatens to overwhelm our civilisation. And it may be that the man to whom the importance of the Optical Works and the creation of the Carl-Zeiss Stiftung is due may have acted in the same spirit as Faust, saying with him:

> " And such a throng I fain would see,—
> Stand on free soil among a people free!"

And the knowledge that in that horrible modern maze—the "social question"—he has been enabled to lighten up and clear a part of the way leading to a better future, gives us the hope and belief that the influence of his life and work will not

> " Through ages from the world depart."

APPENDICES.

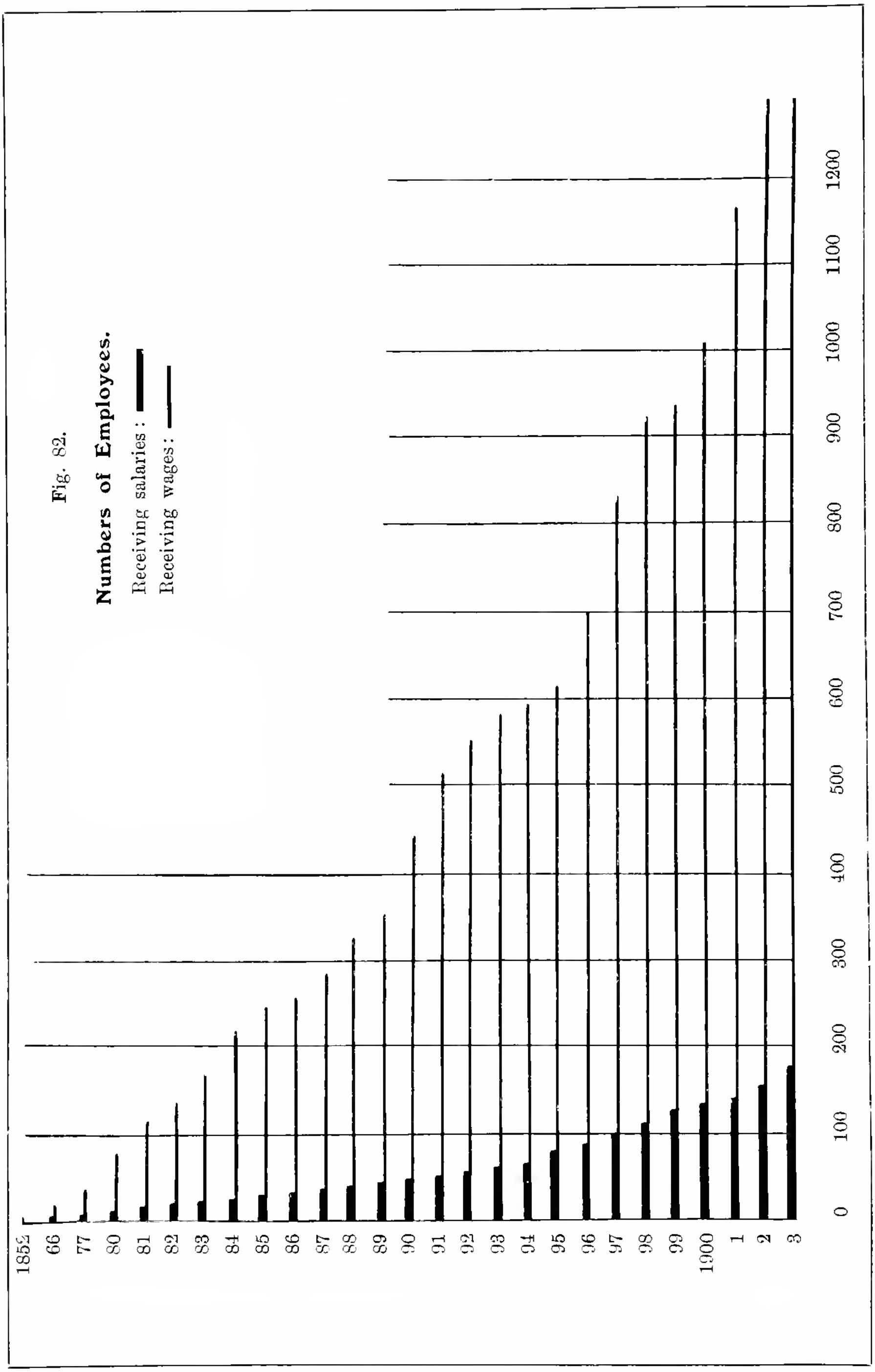


Fig. 82.

Numbers of Employees.

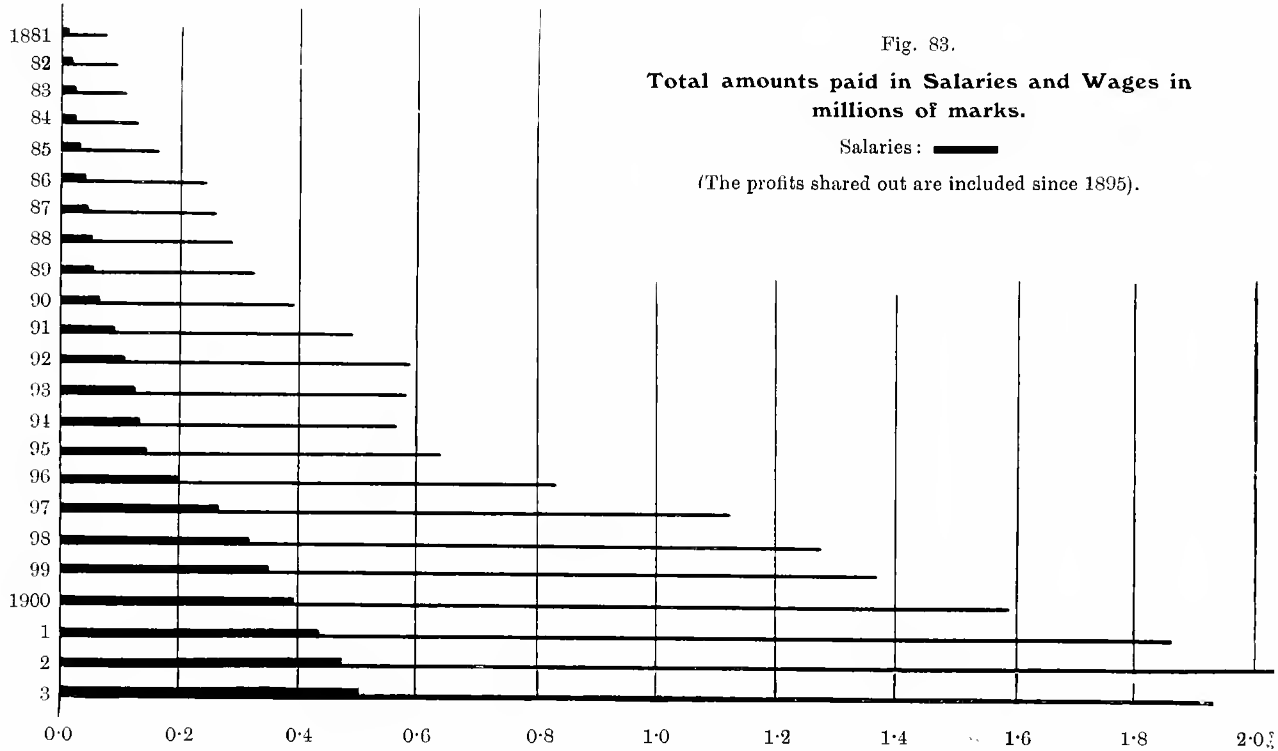


Fig. 83.

Total amounts paid in Salaries and Wages in millions of marks.

(The profits shared out are included since 1895).

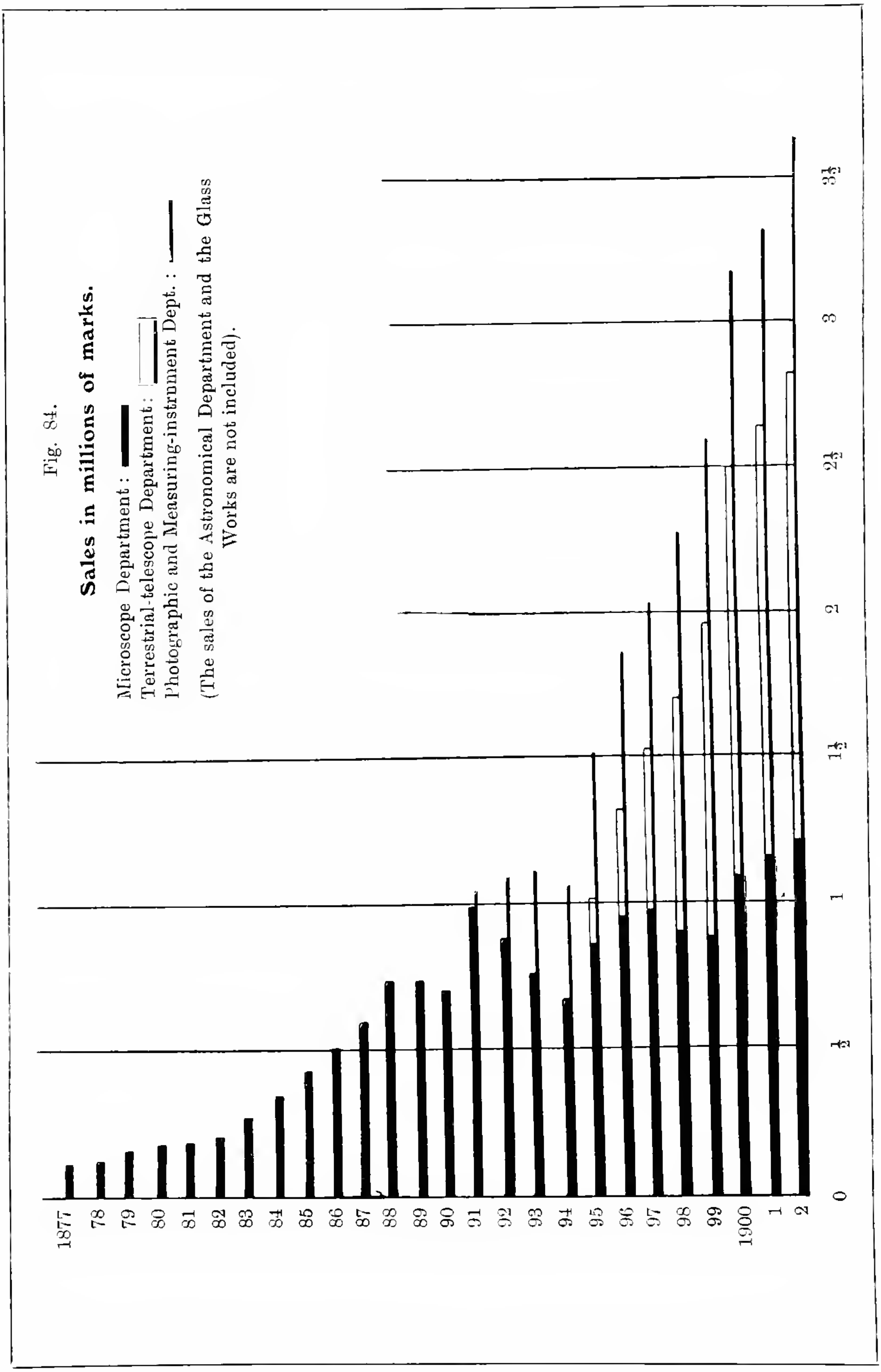


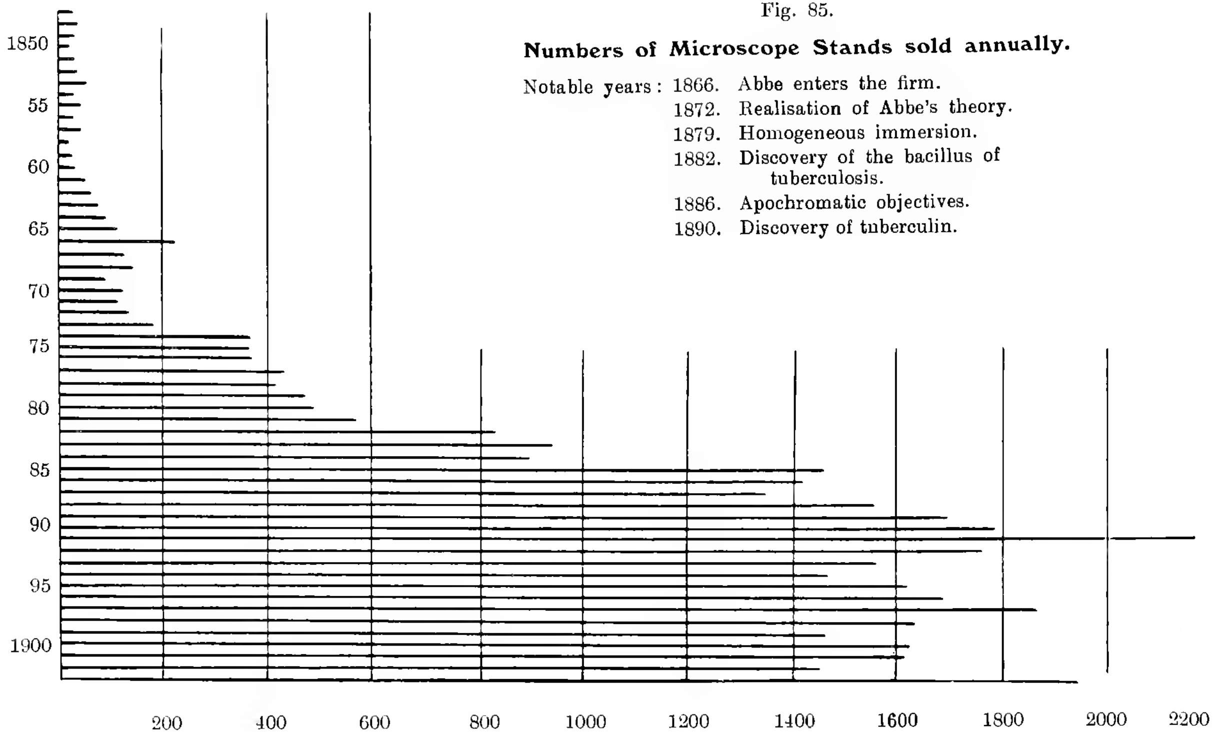
Fig. 84.

Sales in millions of marks.

Fig. 85.

Numbers of Microscope Stands sold annually.

Notable years: 1866. Abbe enters the firm.
1872. Realisation of Abbe's theory.
1879. Homogeneous immersion.
1882. Discovery of the bacillus of tuberculosis.
1886. Apochromatic objectives.
1890. Discovery of tuberculin.



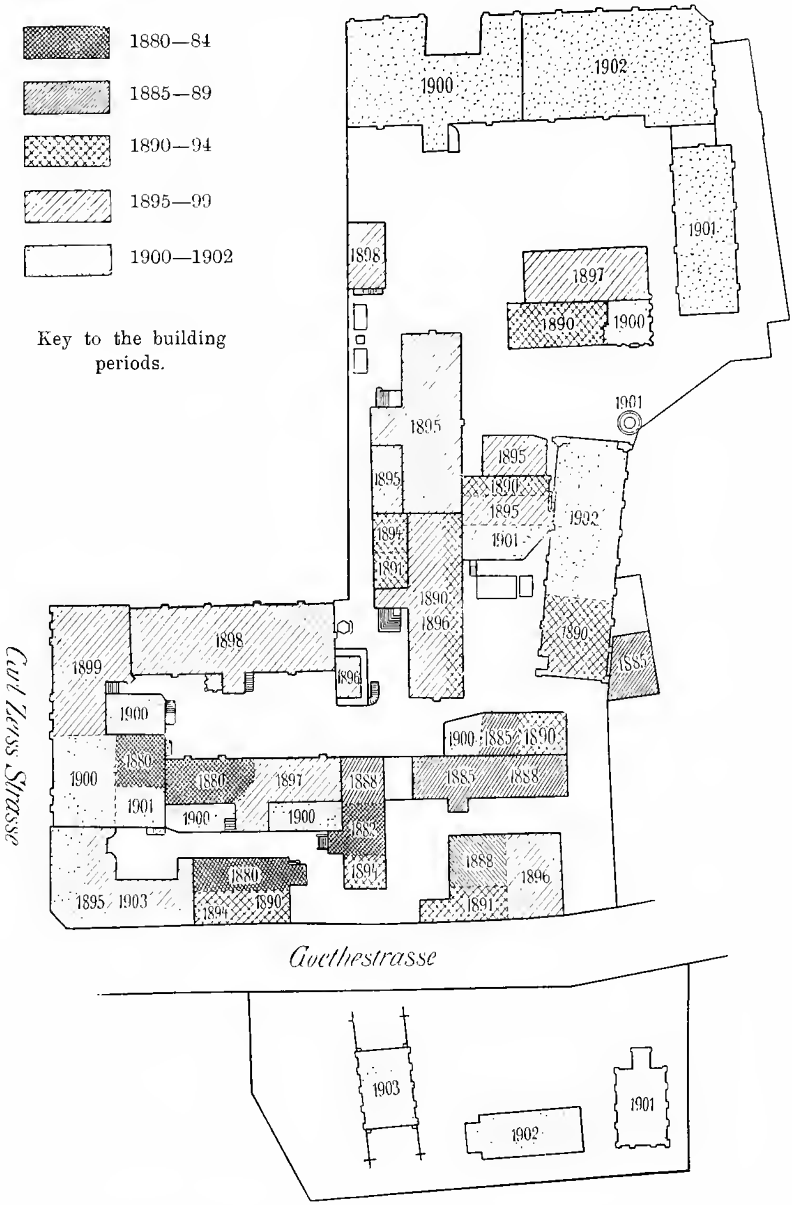


Fig. 86.

Plan showing the development of the Zeiss Works.

A list of the most important Inventions and New Constructions made at Jena.

1868. Abbe introduces his method of microscope construction, consisting in the complete theoretical determination beforehand of the required data.

1872. Abbe's illuminating apparatus for the microscope. (N.A.=1).
Earliest microscope immersion system.

1874. Abbe's refractometer and spectrometer.

1878. Homogeneous immersion system.
Apparatus for counting blood corpuscles.

1881. Abbe's drawing apparatus.

1885. Photomicrographic apparatus.

1885. Apochromatic objectives, compensating eyepieces and projection eyepieces.

1888. Photomicrographic and projection apparatus of a large size.

1889. Monobrom-napthalene immersion system. (N.A.=1·6).

1890. The "anastigmat," later called the "Protar" photographic objective.

1893. Binocular field-glasses and telescopes with erecting prism systems.
Stereo-telemeter and the stereoscopic range-finder.
Butter and milk refractometer.

1894. Sighting telescopes for ordnance.

1895. The "Double Protar" photographic objective.

1896. The "Planar" photographic objective.

1897. Binocular microscope with erecting prism system.

1898. Berger's fine adjustment for the microscope.
The Epidiascope—projection apparatus for transparent and opaque objects.

1899. The "Unar" photographic objective.

1900. Sighting telescopes for rifles.

1901. Pulfrich's Stereo-comparator for astronomical, topographical and metronomical work.

1902. The "Tessar" photographic objective.

1903. The Ultra-microscope.
Verant.

Members of the Board of Management of Carl Zeiss.

Names.	Entered the Optical Works.	Placed on the Board of Management.
Czapski, Dr. Siegfried	1884	1891
Fischer, Max	1890	1895
Schott, Dr. Otto	—	1891
Straubel, Dr. Rudolf (University Professor)	1901	1903

Scientific Collaborators of Carl Zeiss.

Names.	Entered the Optical Works.	Department.
Abbe, Dr. Ernst (University Professor)	1866	1875-1903 Member of the Board of Management.
Ambronn, Dr. Hermann (University Professor)	1899	Principal of the Microscope Department.
Braun, Carl	1900	Terrestrial-telescope Department.
Culmann, Dr. Paul	1900	Scientific Representative of the Firm at Paris.
Dönitz, Emil (Engineer)	1898	Principal of the Patent Department.
Ehlers, Dr. Johann	1903	Research Specialist.
Fischer, Dr. Paul (Solicitor)	1900	Legal Adviser for both Works.
Henker, Dr. Otto	1903	Optical Measurements.
Herschkowitsch, Dr. Mordko	1902	Principal of the Physico-chemical Laboratory.
v. Hofe, Dr. Christian	1903	Terrestrial-telescope Department.
v. Ignatowski, Waldemar	1903	Manager of the Branch at St. Petersburg.
Köhler, Dr. August	1900	Principal of the Projection and Photomicrographic Department
König, Dr. Albert	1894	Principal of the Astronomical and Terrestrial-telescope Department.
Löwe, Dr. Friedrich	1899	Measuring-instrument Department.

Meyer, Franz (Engineer) ...	1903	Technical construction of Astronomical Instruments.
Pauly, Dr. Max	1897	Principal of the Astronomical Department.
Pulfrich, Dr. Carl	1890	Principal of the Measuring-instrument Department.
Riedel, Dr. Paul	1879	Optical Measurements, and Chemico-technical Problems.
v. Rohr, Dr. Moritz ...	1895	Theorist of the Microscopical, Photomicrographic and Projection Departments.
Rudolph, Dr. Paul ...	1886	Principal of the Photographic Department.
Schüttauf, Richard ...	1890	Photographic Department.
Siedentopf, Dr. Henry ...	1899	Research Specialist.
Villiger, Dr. Walter ...	1902	Astronomical Department.
Wandersleb, Dr. Ernst ...	1901	Photographic Department.
Wardall, Frank C.	1903	Demonstrator at the London Branch.

Chronological list of Social and Benevolent Provisions made by the Firm of Carl Zeiss.

1875. 1st Jan.—Foundation of the Carl-Zeiss sick fund, when about 60 people were employed. Conditions:—Compulsory membership; free treatment by own doctor; free medicine; full sick pay for six weeks, half pay for a further six weeks; amount of sick pay fixed at annual meeting of members; only occasional contributions by the firm.

1885. 1st Jan.—Name of sick fund changed to "Betriebskrankenkasse," in accordance with the law of 15th June, 1883, and made to include the Optical Works and the Glass Works. Conditions:—Free choice of doctor; full sick pay for twenty-six weeks, and reduced pay, at the discretion of the management of the fund, for an additional thirteen weeks; amount of sick pay, three-fourths of the amount of wages; the firm to contribute at least a third of the total amount of the contributions prescribed by law; independent management of the fund by the members.

1888. 3rd Dec.—Statute of the superannuation fund of the firms of Carl Zeiss, and Schott & Genossen, nominally dated this day, the day of Carl Zeiss' death, but actually issued somewhat later. Conditions:—Pension in case of continuous incapacity for work due to illness or age, to amount to from 50 per cent. to 75 per cent of the amount of wages on which the pension is calculated; pension for widows to be 2/5ths, and for orphans 1/5th of the pension of the husband and father; the age at which a workman begins to qualify for a pension to be 19; claim after five years' service; highest monthly income to be taken into consideration when calculating the pension, £4, £5 or £6, in the case of a workman, and £5, £6 10s. or £8 in the case of others, according to length of employment; no contributions from employees.

1889. 19th May.—Professor Abbe, out of his private fortune, founded the "Carl-Zeiss Stiftung in Jena"—originally only for University purposes; government confirmation given 21st May.

1891. 1st July.—The "Carl-Zeiss Stiftung" becomes the owner of the Optical Works and part-owner of the Glass Works.

1892. 1st April.—First codification of the workshop rules, the Labour Statute of the Optical Works. Stipulations:—Nine hours' day; guaranteed minimum weekly wages for piece-work also; overtime and Sunday work to be voluntary and at a 25 per cent. increase in the rate of pay.

1892. Autumn.—Arrangements made for a half-yearly medical examination of boys and apprentices, with the object of preventing, or discovering, disease at an early stage.

1893. 1st Jan.—Revision of sick-fund statute. Conditions:—Family insurance with free medical attendance and free medicine; payments in case of death; the firm to pay 5/8ths of the contribution for single men and 3/8ths of that for married men.

1893. 1st April.—Savings bank for employees, especially for juvenile workers, opened; interest paid at the rate of 5 per cent.

1896. 26th Aug.—Statutes of the "Carl-Zeiss Stiftung," signed by Professor Abbe on 26th July, published. Confirmed by the Government on 30th July. Profit-sharing introduced (annual payment of deferred wages or salary); one week's holiday granted per year with pay.

1896. 1st Oct.—Statutes of the "Carl-Zeiss Stiftung" replace the original document of 19th May, 1889. They define the rights and duties of the employees; secure to them complete liberty in the exercise of all personal and political rights; state that wages cannot be reduced, even if the hours of labour are shortened; grant payment for holidays and for absence from work due to fulfilling honorary duties; give compensation of at least half a years' earnings in case of undeserved dismissal; and admit a claim for re-engagement under certain conditions, when the employment has been temporarily broken.

1896. 1st Nov.—Opening of the public reading rooms at Jena, the property of, and managed by, the Reading-Room Association, largely supported by the "Carl-Zeiss Stiftung."

1897. 9th Jan.—Permanent Workmen's Committee for the Optical Works formed.

1897. 1st Sept.—Statute of the Superannuation Fund revised. Pension:—Monthly maximum amount taken into consideration in calculating the pension increased to £5, £6 and £7 in the case of workmen, and to £6, £8 and £10 in the case of others, the qualifying age to be 18; the time of service already spent with the firm, in the case of workmen who have left and been re-engaged, to count in calculating the pension; married workmen to contribute towards the pensions for the families of deceased workmen half the amount of the risk-premium to which the fund is liable. Revision of the Labour Statute:—payment for lost time when on fire drill; payment for overtime for night and Sunday work to be 50 per cent. more than the usual rate.

1900. 12th Feb.—Addendum to the Labour Statute relative to paragraph 616 of the civil code: payment for unavoidable loss of time, for two weeks, in the case of military men, when called to the colours for manœuvres.

1900. 1st April.—Eight hours' day introduced: abolition of breakfast and tea time: total prohibition of alcohol inside the workshops.

1900. 20th April.—Baths for employees opened: bathing allowed during working hours; 10 bathrooms, including 1 for diseased persons. Over 40,000 baths were taken in 1902.

1902. 1st June.—One year's sick pay granted in case of illness, if it should continue for so long a period.

1902. 1st Sept.—Foundation of supplementary sick fund by the employees to make up sick pay to total amount of wages.

1902. 20th Sept. to 12th Oct.—Handing over of the rooms of the newly-built "People's Institute" to the Reading Room Association and to the Grand-Ducal Technical Schools.

1903. 1st Nov.—Opening of the large hall of the People's Institute.

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